

## NASA Contractor Report 159241

(NASA-CR-159241) DESIGN AND FABRICATION OF  
TITANIUM MULTI-WALL THERMAL PROTECTION  
SYSTEM (TPS) TEST PANELS Contractor Report,  
Jan. - Aug. 1979 (Rohr Industries, Inc.,  
Chula Vista) 66 p HC A04/MP A01 CSCI 20K G3/39 23636

NO-26695

Unclass  
23636

DESIGN AND FABRICATION OF TITANIUM MULTI-WALL  
THERMAL PROTECTION SYSTEM (TPS) TEST PANELS

Winford Blair, John E. Meaney, Jr., and  
Herman A. Rosenthal

ROHR INDUSTRIES, INC.  
Chula Vista, California 92012

NASA Contract NAS1-15646  
February 1980



National Aeronautics and  
Space Administration

Langley Research Center  
Hampton Virginia 23665

TASK 1 REPORT

DESIGN AND FABRICATION OF TITANIUM MULTI-WALL THERMAL  
PROTECTION SYSTEM (TPS) TEST PANELS

Prepared for:  
NASA LANGLEY RESEARCH CENTER  
Hampton, Virginia 23665

CONTRACT NAS1-15646

ROHR INDUSTRIES, INC.  
Chula Vista, CA.

## FOREWORD

This is the interim report on work being performed by Rohr Industries - Design and Fabrication of Titanium Multiwall Thermal Protection System (TPS).

This program is administrated by the National Aeronautics Administration Langley Research Center (NASA LaRC). Mr. John Shideler of the Thermal Structures Branch, Structures and Dynamics Division, is Technical Monitor for the program.

The following Rohr personnel were the principal contributors to the program during this reporting period: Winn Blair, Program Manager; T. C. Atkinson, Manufacturing Technology; J. E. Meaney, Structures; R. M. Martinez, Project Engineer; H. A. Rosenthal, Thermal Testing; R. H. Timms, Preliminary Design; and L. A. Wiech, Engineering Laboratory. Overall program responsibility is assigned to the Rohr Aerospace R&D Engineering Organization with U. Bockenbauer, Manager.

## TABLE OF CONTENTS

	Page
SUMMARY . . . . .	1
INTRODUCTION . . . . .	1
DESIGN DEFINITION . . . . .	2
CONCLUSIONS . . . . .	10
APPENDIX . . . . .	A-1
"Thermal Conductivity Test Report By General Dynamics Convair Division"	

## LIST OF FIGURES

Figure Number		Page
1.	Task 1 Program Status . . . . .	11
2.	Task 2 Program Status . . . . .	12
3.	Design, Nine-Panel Array . . . . .	13
4.	Design, Two-Panel Array . . . . .	14
5.	Design, Panel Assembly . . . . .	15
6.	Design, Skin Forming Tool . . . . .	16
7.	Design, Dimpled Sheet Forming Tool . . . . .	17
8.	Superplastically Formed Dimpled Sheet . . . . .	18
9.	Superplastic Form Tool Ready for Loading Into Vacuum Furnace . . . . .	19
10.	Dimpled Sheet Prepared for Chem Blanking . . . . .	20
11.	Plated Dimpled Sheet . . . . .	21
12.	Multiwall Panels LID Bonded For Test Specimens . . . . .	22
13.	Flatwise Tension Test Specimen Layout . . . . .	23
14.	Beam Flexure Test Specimens Layout . . . . .	24
15.	Beam Flexure Test Specimen Layout . . . . .	25
16.	Superplastically Formed Skin . . . . .	26
17.	Skin Form Tool . . . . .	27
18.	Plated Skin . . . . .	28
19.	Dimpled Sheets, Septum Sheets and Skins Prepared for Assembly . . . . .	29
20.	Vacuum Tight Panel Test Panel Being Aided for LID Bonding . . . . .	30
21.	LID Bonded Panel (Vacuum Tight Evaluation) . . . . .	31
22.	Emittance Test Results . . . . .	32
23.	Test Fixture For Flatwise Tension Tests . . . . .	33
24.	Test Set Up For Hot Beam Flexure Tests . . . . .	34
25.	Creep Test Results . . . . .	35

# LIST OF TABLES

Table Number		Page
1.	Emittance Test Data . . . . .	36
2.	Flatwise Tension Tests - Separate Layers of Sandwich . . . . .	37
3.	Flatwise Tension Tests - Full Depth Sandwich . . . . .	38
4.	Basic Face Sheet Tension Test - Room Temperature . . . . .	39
5.	Beam Flexure Tests . . . . .	40

## SUMMARY

A Titanium Multiwall Thermal Protection System (TPS) panel conceived by NASA was designed. An acceptable fabrication process was developed, and the panel design was verified through mechanical and thermal testing of component specimens.

## INTRODUCTION

Rohr Industries was awarded a contract January 1979 to design and fabricate titanium multiwall thermal protection panels for testing by NASA. Progress, current activities, and future milestones are shown in Figures 1 and 2.

The primary objective of this program is to design and fabricate metallic multilayer sandwich panels for test and evaluation by NASA. The program consists of two tasks:

Task 1 - Design Definition

Task 2 - Test Model Design and Fabrication

Task 1 consists of a preliminary design of panels and tools, fabrication of test panels and testing in face tension, flexural strength, creep, thermal conductivity and emittance.

In Task 2, a nine panel array shown in Figure 3, will be fabricated for testing in the Langley Research Center 8-foot High Temperature Structures Tunnel. A two-panel array shown in Figure 4 will be fabricated and delivered to the Langley Research Center for vibrational and acoustical tests. A second two-panel array will be delivered to Johnson Space Center for radiating tests.

Only the activities of Task 1 will be described in this report.

## DESIGN DEFINITION

The configuration and construction details for a titanium multiwall panel is shown in Figure 5. The panel is a nine-sheet sandwich structure consisting of an upper and lower face sheet, four dimpled sheets, three septum sheets, and clips for attachment to the test fixture. The material for all detail parts is Ti-6Al-4V. The joining system used is a Rohr proprietary process in which the interfaces of the parts to be joined are plated with two or more elements. When put in contact with each other and heated to approximately 1214K (1725°F), the plating material melts creating a short time eutectic with the Ti-6Al-4V. While holding at this temperature for a specified time the plating material is diffused into the Ti-6Al-4V creating a bond at all plated interfaces.

## DESIGN

Panel Design - The panel assembly shown in Figure 5 was designed from a sketch and information supplied by NASA Langley Research Center, Hampton, Virginia. Particular attention was given to the fabrication problem encountered with forming of the dimpled sheets. The design in Figure 5 shows a 25.75° angle on all sides of the panel. The angle slope is in the flow direction and also permits the use of a common dimpled sheet used in each of the four layers. The design is also unique inasmuch as the outer skins are formed on the 25.75° angle and are joined to each other by Liquid Interface Diffusion bonding to close out the panel's four sides. The panel sides are corrugated to give stiffness and to allow the panels to nest during the time they are being thermally expanded during service.



Skin Forming Tool Design - The tool design shown in Figure 6 takes into account the possibility of mass producing the skins. The design allows for multiple loading parts into mirror image die halves and forming as many as six skins simultaneously. Argon gas is used as the pressure media for superplastic forming the skins.

Dimpled Sheet Forming Tool Design - The design shown in Figure 7 takes into account Ti-6-4 material size availability, thermal expansion and part quantity. The die plates were designed to permit economic installation of a large number of pins. A shim plate was added to permit some adjustment of the dimple height by adding to or removing from the plate.

#### TEST PANEL FABRICATION

Panels for Structural and Thermal Tests - The dimpled sheet shown in Figure 8 was superplastically formed in a vacuum furnace using 8.27 KPa (1.2 pounds per square inch) dead weight pressure. Figure 9 shows the dimpled sheet forming tool being loaded into the vacuum furnace. After it was formed, the dimpled sheet was trimmed by chem blanking, (see Figure 10), and was plated on the nodes only using the Rohr proprietary process. The plating parameters were established using full sized sheets 305 mm (12") by 610 mm (24"). Figure 11 shows a plated sheet with cut-outs made for microexamination.

The layup for LID bonding was accomplished by aligning the nodes opposing each other through the septum sheets, and by resistance welding at each of the four corners. This procedure held the dimpled sheets, septum sheets and skins in position for LID bonding. For LID bonding, the layup was placed on a flat graphite reference block, with 18 mm (.7") thick blocks placed on each of the four sides. The side blocks control the panel height and prevent the panel from being crushed by a graphite block that was placed on top of the layup for bonding pressure. The assembly was then placed into a vacuum furnace for LID bonding. The

furnace was evacuated to  $1 \times 10^{-5}$  torr, heated to 1214K (1725°F), and held for a specific period of time. During this period the plated material is melted and diffused into the Ti-6Al-4V creating a bond joint at all plated interfaces.

All panels were fabricated without clips and doublers. All panels for testing in flatwise face tension, beam flexure, creep and thermal conductivity were LID (Liquid Interface Diffusion) bonded in sizes of 152 mm (6") by 305 mm (12") and 305 mm (12") by 305 mm (12"). Figure 12 shows three of these panels.

After the panels were LID bonded a layout for cutting of all the test specimens was made. The layout for the structural test specimens is shown in Figures 13, 14 and 15. The test specimens were cut using an electric discharge saw. Specimens for static creep test were taken from each material gage used in the sandwich. Two thermal conductivity test specimens were cut to a size 1.8 by 203 by 203 mm (.7" x 8" x 8"). The emittance test specimen, .076 by 50 by 100 mm (.003" x 2" x 4"), was polished to a very high luster on one end and processed through two thermal cycles, duplicating the fabrication process, then checked for emittance on both the polished and unpolished areas. One specimen was oxidized for 30 minutes at 810K (1000°F) and checked for emittance.

Vacuum Tight Panel Fabrication - This was a test to determine if a vacuum tight panel can be produced. The dimpled sheets and septum sheets were produced in the same manner as for the structural test panels. The skins which also close out the vacuum tight panel sides shown in Figure 16 were superplastically formed two at a time in a mirror image die, shown in Figure 17. The forming was also accomplished in a vacuum furnace using 34.5 KPa (5 pounds per square inch) argon gas pressure. The skins for the vacuum tight panel were plated around the periphery 5.1 mm (0.2") wide shown in Figure 18.

After plating had been accomplished the skins, septum sheets, and dimpled sheets shown in Figure 19 were assembled for LID bonding. The nodes were aligned opposing each other through the septum sheets, and resistance spot welded five places at each corner. This procedure held the detail parts in place until the joint had been achieved by the LID bonding process. For LID bonding, the assembly was placed on a flat graphite reference surface shown in Figure 20. Also shown in Figure 20 are the graphite aids that are used to control the panel height and bonding pressure. The panel was isolated from the graphite by commercially pure titanium slip sheets. The assembly was then placed into a vacuum furnace for LID bonding. The furnace was evacuated to  $1 \times 10^{-5}$  torr, then heated to 1214K (1725°F) and held for a specific time. During this time period the plated material is melted and diffused into the Ti-6Al-4V creating a bond joint at all plated interfaces. Figure 21 shows a LID bonded panel for vacuum tight evaluation.

#### THERMAL TESTING

Emittance Tests - The samples tested were:

Sample #7910 - as received foil.

Sample #7911 - foil run through sandwich manufacturing process.

Sample #7912 - foil was polished, then run through sandwich manufacturing process.

Sample #7904 - foil oxidized at 810K (1000°F) for 30 minutes.

These samples were supplied to General Dynamics for wavelength-reflectivity measurements in their test apparatus described in the appendix. All tests were made at room temperature. Reflectivity data were entered into their computer program which determined total normal emittance at various temperatures. Results are given in Table I and graphed in Figure 22. Note that the term emissivity is the same as total normal emittance.

For the most part only minor differences are shown between the samples. There appears to be a slight increase in emittance when the sample goes through the manufacturing process, i.e. compare 7910 and 7911. But polished foil 7912 shows an even smaller difference. As expected, the foil oxidized for 0.5 hours at 810K (1000°F) has a higher emittance. Additional tests have shown that emittance continues to increase as oxidation time increases above 0.5 hours.

In summary, one can conclude that little is gained by polishing the foil, and that manufacturing the sandwich out of as received foil is satisfactory. Furthermore, additional data will be required to determine emittance as a function of oxidation time.

Conductivity Tests - Thermal Conductivity testing was subcontracted to General Dynamics Convair Division. Tests were performed on two panels having approximate dimensions of 17.3 by 203 by 203 mm (.68" by 8" by 8") using a guarded hot plate apparatus, see Appendix A.

The test results showed higher conductivity than had been predicted. After analyzing the test data and test conditions, it was concluded that:

1. The test panel was too small.
2. Tests should be re-run by Rohr using a larger test panel, 17.3 by 305 by 305 mm (.68" by 12" by 12").
3. The test should use a standard material (MIN-K) with a known thermal conductivity next to the test panel.
4. The heating instrument should be capable of holding finite temperature control over the test area.

(Data from these Rohr tests have been added to the figure in the Appendix. This data fall about 10 percent higher than that predicted from NASA CP-2065).

## STRUCTURAL TESTING

Flatwise Tension Tests - Test specimens were approximately 50 by 50 mm (2" by 2") and consisted of full depth sandwich and individual layers. These specimens were bonded with Hysol EA934 adhesive to aluminum loading blocks. The blocks with the specimen were loaded into the test fixture as shown in Figure 23. This fixture was located in the Instron test machine. This set-up has swivel joints at both ends to account for misalignments of load. However this device must overcome friction loads and these small loads can be very significant if they apply peel loads to this sandwich configuration (see test results). Therefore for future testing it is recommended that fixtures more sensitive to alignment be used.

The test results are summarized in Tables 2 and 3. The lower values in the full depth sandwich (Table 3) are indicative of predominant LID bond failures rather than node metal failures. However the three very low values in the individual layer testing (specimens 16-2, 22-2, and 24-4) are not indicative of weakness in the bonding. These specimens had significant metal failures, and it is suspected that their premature failure was caused by a peel load introduced by the loading fixture (see above discussion). There was a range in the number of nodes per specimen, however there did not appear to be any correlation between their number and the failure stress.

Basic Face Sheet Tension Tests - The specimens are standard ASTM E8 size with a 12.7 mm (.50") wide test area. The specimens were of three different thicknesses: .038, .076 and 0.10 mm (.0015", .003" and .004"), and were tested in three physical conditions: a) as received from the mill, b) after being run through the LID thermal cycle 1200K (1700°F) for approximately 90 min., and c) sheets taken from actual bonded sandwich panels. These specimens were tested at room temperature in the Instron test machine and the following properties were determined:

yield and ultimate stress, percentage elongation, and modulus of elasticity.

The test results are summarized on Table 4. As shown, the as received strength properties are significantly higher than those for standard annealed Ti-6Al-4V sheet. These increases are attributed to the rolling operations these sheets received before being sent to Rohr. The specimens after the LID thermal cycle produced strength properties close to annealed sheet values. The low elongation value in the 0.038 mm (.0015") foil indicates some contamination during the thermal cycle. The .038 mm (.0015") and .076 mm (.003") specimens from the LID bonded panels exhibited lower strength and very low elongation properties. This did not occur in the 0.10 mm (.004") sheet. It is surmised that the .10 mm (.004") sheet is not as sensitive to surface contamination from the furnace and to the diffusion bonding as the thinner sheets.

Beam Flexure Tests - The seven test specimens had the following approximate dimensions: 305 by 76 by 17 mm (12" by 3" by .65"). All seven specimens were tested in the test setup shown in Figure 24. This setup was designed to provide a temperature gradient across a specimen while it is being subjected to a four point beam flexure test. As shown, the hot side of the specimen was heated by quartz lamps while the other side was cooled by shop air. The heat in the lamps may be regulated by altering the input current and shop air flow is metered by a valve. Ti-6Al-4V pads 12.7 mm (1/2" wide by .050" thick) were used to distribute applied and reaction loads into the specimens. Two of the specimens were tested at room temperature and did not require thermocouple instrumentation. Each of the other five specimens had eight thermocouples installed.

Two room temperature specimens were loaded in 89.0 N (20 lb.) increments with a return to zero load after each increment. The loads were applied with a crosshead movement of .05 in/minute and the load was held for

30 sec. Deflection readings at the center of the specimen were taken at each loading and unloading.

Four of the five remaining specimens were tested to failure in the same manner as described above except a temperature gradient was imposed. Two specimens had a 422-700K (300°-800°F) gradient and the other two had a 422-811K (300°F-1000°F) gradient. These specimens were brought to temperatures before the loads were applied. The seventh specimen was brought to a temperature gradient of 422-811K (300°-1000°F) and then a total load of 120.0 N (27 lbs.) was imposed and left for one hour. There was a negligible amount of creep during the test.

The results are shown in Table 5. Note the very small temperature gradients along the lengths of the specimens. The disbond failure mode on the room temperature specimens occurred only after very severe buckling waves took place in the face sheet. Deflection readings indicate that permanent set and creep values were negligible.

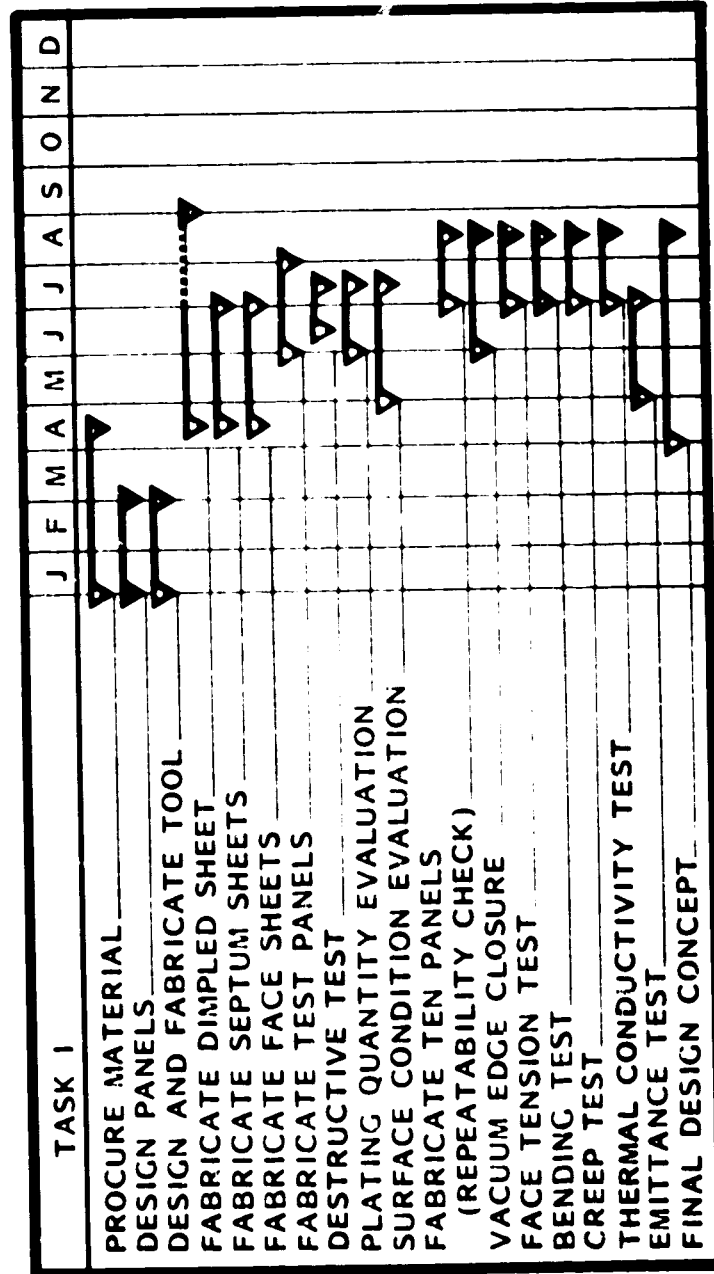
Creep Tests - A total of eight specimens were tested for elevated temperature creep. The specimens were .076 mm (.003 in.) foil which had been diffusion bonded to corrugated core. After the core had been cut away, the foil was cut into tensile specimens. The specimens were dead weight loaded and a portable wrap around furnace supplied the temperature. Deflection was measured using a dial gage and a microscope. Three of the eight specimens were tested at 811K (1000°F) and 68.95 MPa (10,000 psi) for 100 hours without failure. The other five specimens were tested at higher stress levels and the results are plotted on Figure 25. Comparison of the data for LID bonded foil with published rupture data for annealed sheet indicates about a 25 percent reduction in creep rupture due to the LID bonding process and loss of work hardening imposed on the material by the rolling operation.

## CONCLUSIONS

1. A design was completed which takes into consideration fabrication techniques, thermal properties, mechanical properties, and material availability.
2. An acceptable fabrication process was developed.
3. The design was verified through mechanical and thermal testing of the materials and sandwich test specimens.



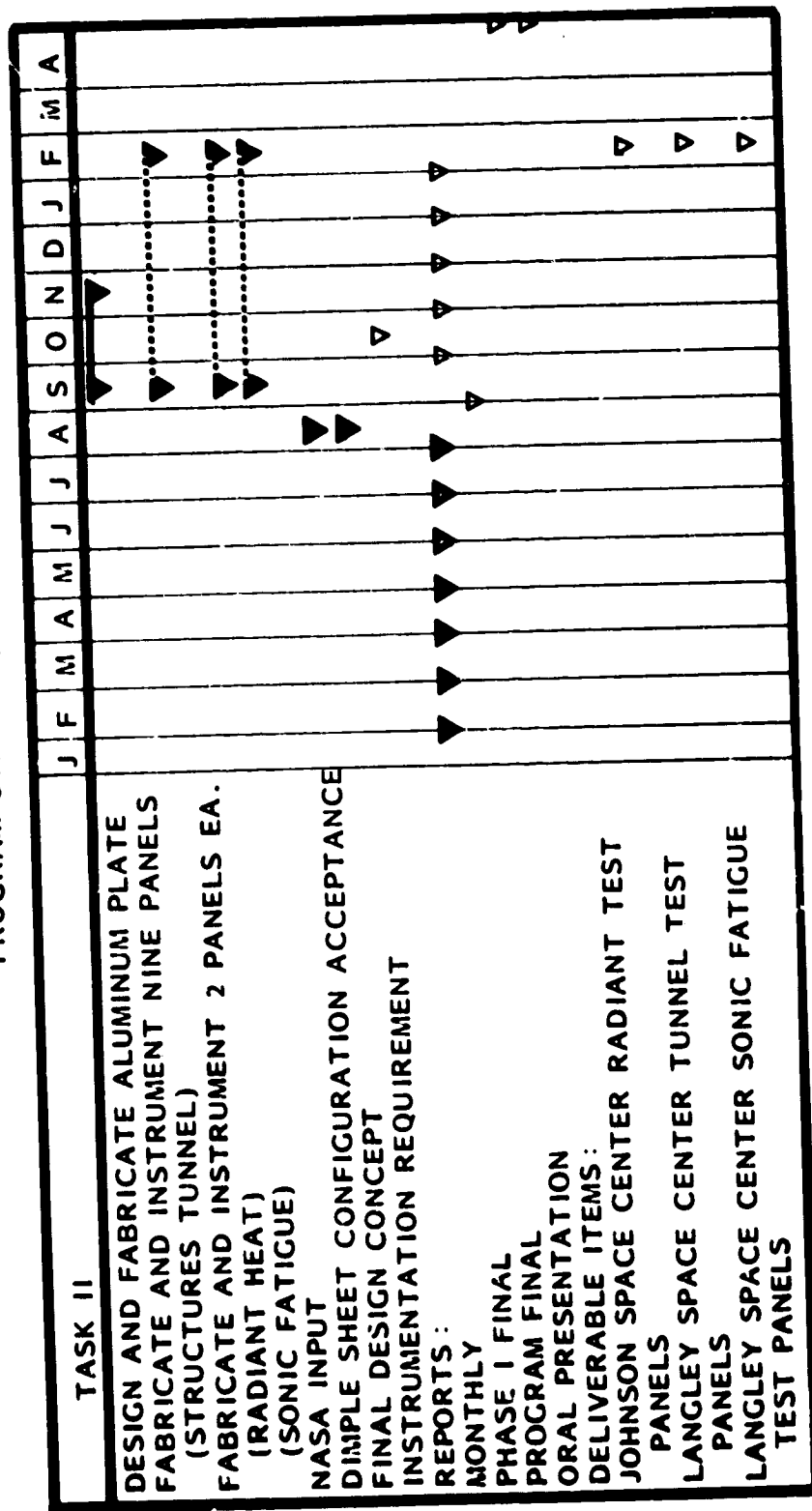
TPS  
PROGRAM STATUS



144049

Figure 1. Task 1 Program Status

TPS  
PROGRAM STATUS (CONT'D)



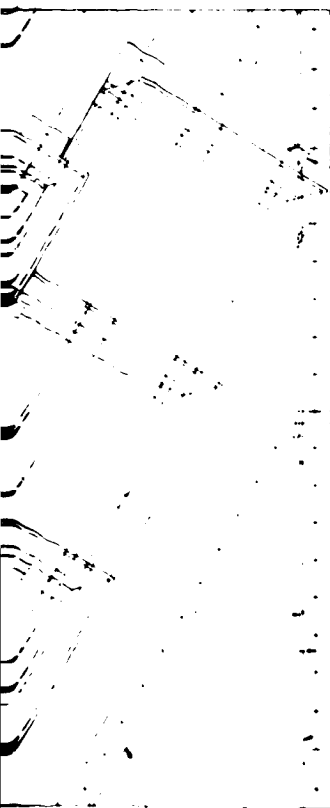
144050

Figure 2. Task 2 Program Status





44-38861-100



2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091 2092 2093 2094 2095 2096 2097 2098 2099 2100 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148 2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164 2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175 2176 2177 2178 2179 2180 2181 2182 2183 2184 2185 2186 2187 2188 2189 2190 2191 2192 2193 2194 2195 2196 2197 2198 2199 2200 2201 2202 2203 2204 2205 2206 2207 2208 2209 2210 2211 2212 2213 2214 2215 2216 2217 2218 2219 2220 2221 2222 2223 2224 2225 2226 2227 2228 2229 2230 2231 2232 2233 2234 2235 2236 2237 2238 2239 2240 2241 2242 2243 2244 2245 2246 2247 2248 2249 2250 2251 2252 2253 2254 2255 2256 2257 2258 2259 2260 2261 2262 2263 2264 2265 2266 2267 2268 2269 2270 2271 2272 2273 2274 2275 2276 2277 2278 2279 2280 2281 2282 2283 2284 2285 2286 2287 2288 2289 2290 2291 2292 2293 2294 2295 2296 2297 2298 2299 2300 2301 2302 2303 2304 2305 2306 2307 2308 2309 2310 2311 2312 2313 2314 2315 2316 2317 2318 2319 2320 2321 2322 2323 2324 2325 2326 2327 2328 2329 2330 2331 2332 2333 2334 2335 2336 2337 2338 2339 2340 2341 2342 2343 2344 2345 2346 2347 2348 2349 2350 2351 2352 2353 2354 2355 2356 2357 2358 2359 2360 2361 2362 2363 2364 2365 2366 2367 2368 2369 2370 2371 2372 2373 2374 2375 2376 2377 2378 2379 2380 2381 2382 2383 2384 2385 2386 2387 2388 2389 2390 2391 2392 2393 2394 2395 2396 2397 2398 2399 2400 2401 2402 2403 2404 2405 2406 2407 2408 2409 2410 2411 2412 2413 2414 2415 2416 2417 2418 2419 2420 2421 2422 2423 2424 2425 2426 2427 2428 2429 2430 2431 2432 2433 2434 2435 2436 2437 2438 2439 2440 2441 2442 2443 2444 2445 2446 2447 2448 2449 2450 2451 2452 2453 2454 2455 2456 2457 2458 2459 2460 2461 2462 2463 2464 2465 2466 2467 2468 2469 2470 2471 2472 2473 2474 2475 2476 2477 2478 2479 2480 2481 2482 2483 2484 2485 2486 2487 2488 2489 2490 2491 2492 2493 2494 2495 2496 2497 2498 2499 2500 2501 2502 2503 2504 2505 2506 2507 2508 2509 2510 2511 2512 2513 2514 2515 2516 2517 2518 2519 2520 2521 2522 2523 2524 2525 2526 2527 2528 2529 2530 2531 2532 2533 2534 2535 2536 2537 2538 2539 2540 2541 2542 2543 2544 2545 2546 2547 2548 2549 2550 2551 2552 2553 2554 2555 2556 2557 2558 2559 2560 2561 2562 2563 2564 2565 2566 2567 2568 2569 2570 2571 2572 2573 2574 2575 2576 2577 2578 2579 2580 2581 2582 2583 2584 2585 2586 2587 2588 2589 2590 2591 2592 2593 2594 2595 2596 2597 2598 2599 2600 2601 2602 2603 2604 2605 2606 2607 2608 2609 2610 2611 2612 2613 2614 2615 2616 2617 2618 2619 2620 2621 2622 2623 2624 2625 2626 2627 2628 2629 2630 2631 2632 2633 2634 2635 2636 2637 2638 2639 2640 2641 2642 2643 2644 2645 2646 2647 2648 2649 2650 2651 2652 2653 2654 2655 2656 2657 2658 2659 2660 2661 2662 2663 2664 2665 2666 2667 2668 2669 2670 2671 2672 2673 2674 2675 2676 2677 2678 2679 2680 2681 2682 2683 2684 2685 2686 2687 2688 2689 2690 2691 2692 2693 2694 2695 2696 2697 2698 2699 2700 2701 2702 2703 2704 2705 2706 2707 2708 2709 2710 2711 2712 2713 2714 2715 2716 2717 2718 2719 2720 2721 2722 2723 2724 2725 2726 2727 2728 2729 2730 2731 2732 2733 2734 2735 2736 2737 2738 2739 2740 2741 2742 2743 2744 2745 2746 2747 2748 2749 2750 2751 2752 2753 2754 2755 2756 2757 2758 2759 2760 2761 2762 2763 2764 2765 2766 2767 2768 2769 2770 2771 2772 2773 2774 2775 2776 2777 2778 2779 2780 2781 2782 2783 2784 2785 2786 2787 2788 2789 2790 2791 2792 2793 2794 2795 2796 2797 2798 2799 2800 2801 2802 2803 2804 2805 2806 2807 2808 2809 2810 2811 2812 2813 2814 2815 2816 2817 2818

DATE: 10/10/78 BY: J. J. J. (J. J. J.)

2. DISTANCES

WATER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
WATER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
WATER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
WATER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

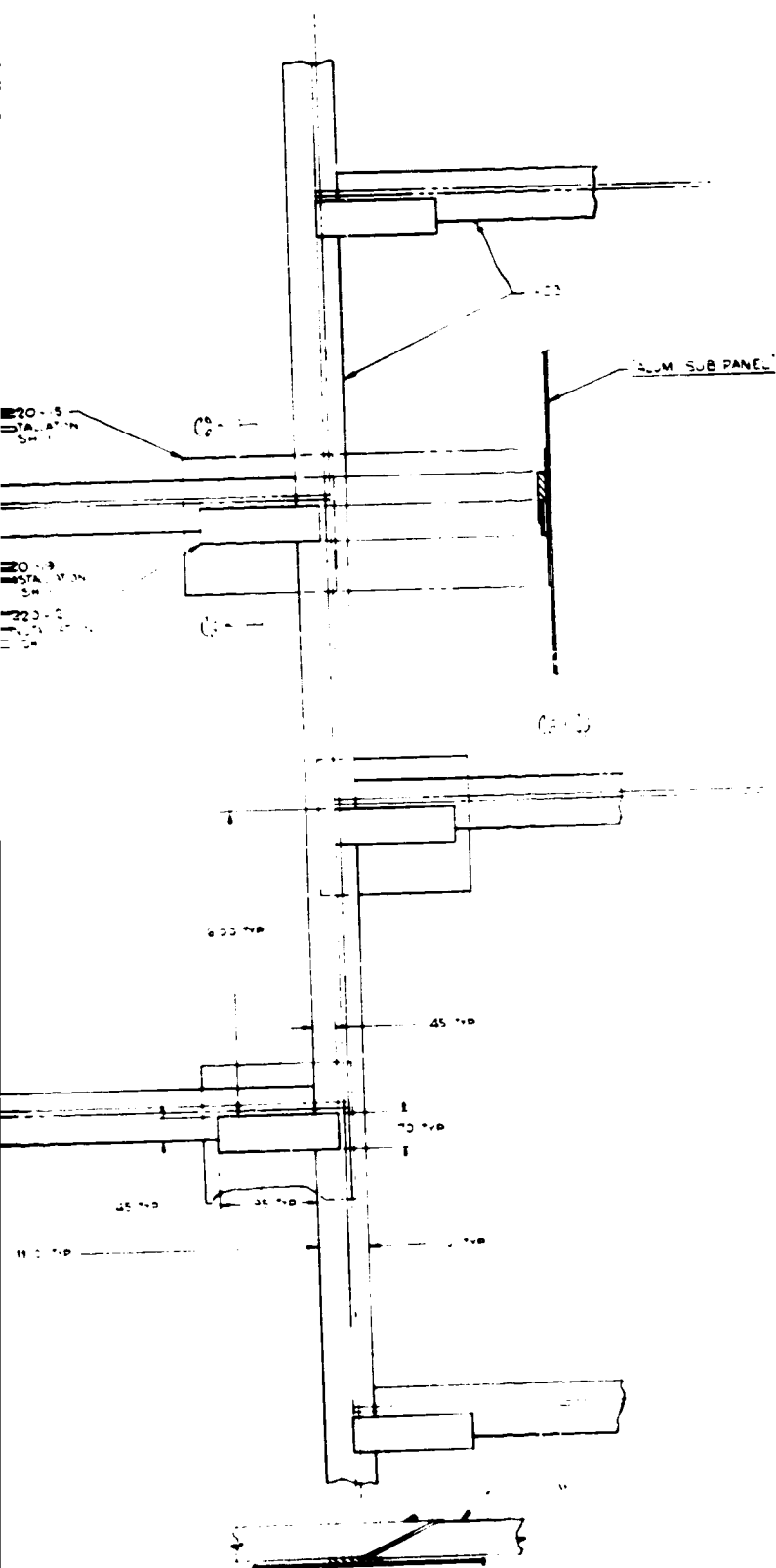
5. PER METER

100 PER METER

[illegible]

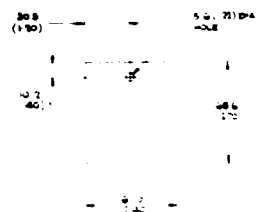
Figure 3. Design, Nine-Panel Array  
(Construction Details)  
(Sheet 1 of 2)



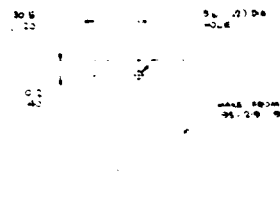


13a

Figure 3. Design, Nine-Panel Array  
(Construction Details)  
(Sheet 2 of 2)



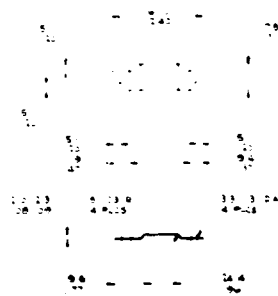
DETAIL 17



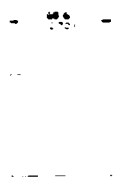
DETAIL 18



DETAIL 19



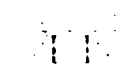
DETAIL 20



DETAIL 21



DETAIL 22



23

24

847 12.3 1.44 80.7  
8.12 80.7  
1.1 80.7

95-12-301

50 ASSEMBLY

POLYXIT FRAME



80-11-3-44 BOW  
80-35-10-7  
80-35-10-7

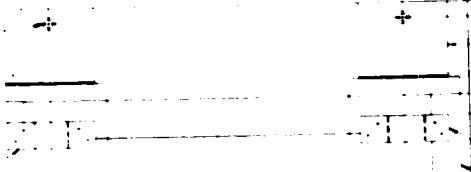
45 19 50

30 5 10

346 7 (15 73)  
141 3 (9 50)

10 7 40

1. 21. 3A-100E  
2. 14. 140 8 DE  
3. 9. 79 2A +  
4. 14. 140 8 DE  
5. 14. 140 8 DE



17  
18

19  
20

21  
22

23  
24

25  
26

27  
28

29  
30

31  
32

33  
34

35  
36

37  
38

39  
40

41  
42

43  
44

45  
46

47  
48

49  
50

51  
52

53  
54

55  
56

57  
58

59  
60

61  
62

63  
64

65  
66

67  
68

69  
70

71  
72

73  
74

75  
76

77  
78

79  
80

81  
82

83  
84

85  
86

87  
88

89  
90

91  
92

93  
94

95  
96

97  
98

99  
100

101  
102

103  
104

105  
106

107  
108

109  
110

111  
112

113  
114

115  
116

117  
118

119  
120

121  
122

123  
124

125  
126

127  
128

129  
130

131  
132

133  
134

135  
136

137  
138

139  
140

141  
142

143  
144

145  
146

147  
148

149  
150

PLATE ASSY

FOLDOUT FRAM. 2

... ..

299 72  
( 800 )

33 3, 2 45 R 43°  
-AMER. 4 P. 15

DETAIL of -17  
SCALE 1:2

559  
(220)

305  
(120)

53  
(2.1)

1. 12' 1 ON  
FLAT PATTERN  
4 1/2

2 3 2 3  
(26 29)  
2 1  
(23)

21 1  
i 43)

127  
50)

3  
05)

224  
(88)

4544

B. 23) R  
TYP 4 PLCS

DETAIL of - 23

11

58  
23

- (24) -

DETAIL of -21

610  
(242)

(42)

456

LOGGLE  
51 272

 $\angle A = 30^\circ$ 

2. 3 80'

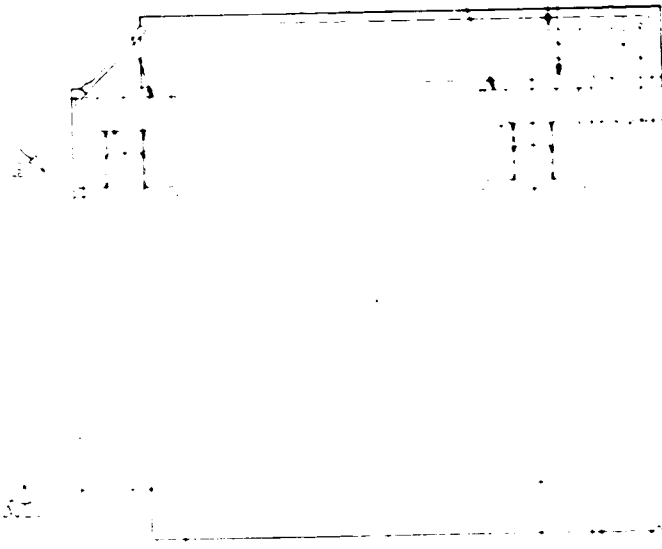
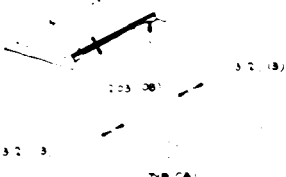
DETAIL 2 - 19

28-21

29-1-9

UPPER SHAPED SHEET  
LOWER SHAPED SHEET  
ALTERNATE SHEETS  
PLACED SIDEWAYS  
SO THAT HOLES MATCH

3, 5' RAD



5.1 (30)

104.48

(13) 156 R 45°  
NUMBER 4 PLCS



2.500

3.0



1.90

51 RAD 30°

3.1 3.

3.3 3. R 2 PLCS

40. R 2 PLCS

20 3.00

30 5. 20

30.48 (200. REF

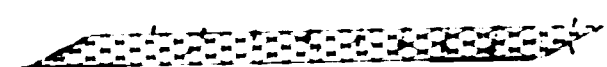
24.30 (9.500)

35.86 (400)

501 PANEL ASSEMBLY

11 15 17 18 19 20 21 22

23 24 25 26 27 28 29 30



FILE 1-19

50

1 DIMENSIONS IN G.2. UNITS AND (CUSTOMARY  
UNITS) mm (in) cm (in) m (ft) yd (ft) mi (mi)

- [illegible]

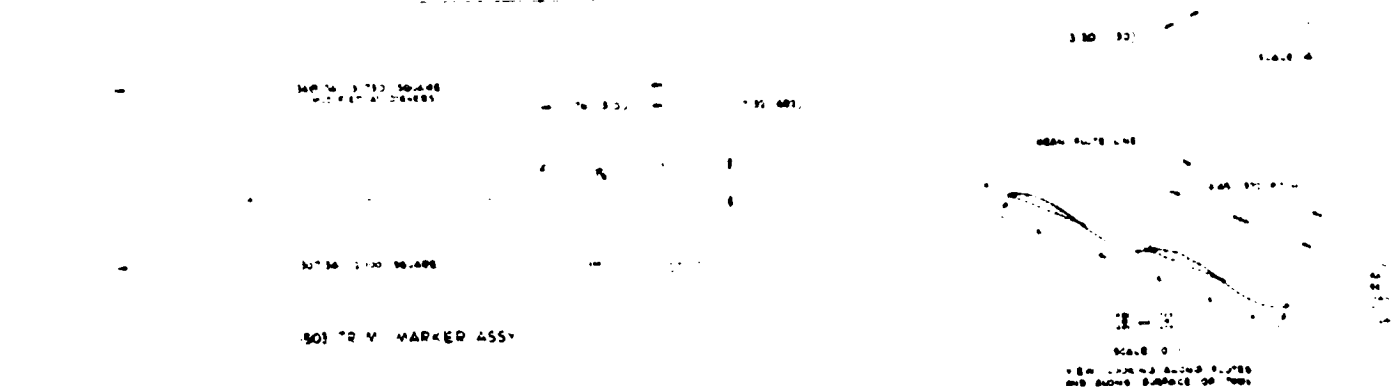
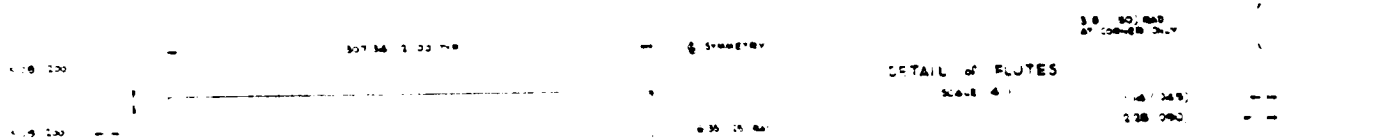
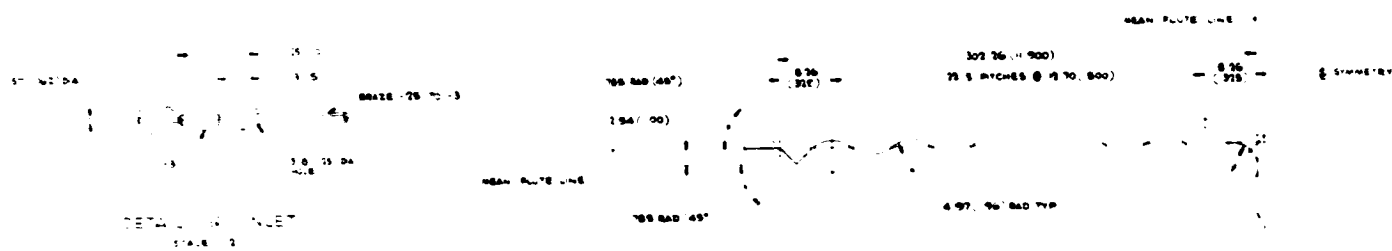
OF FOUR QUALITY

[illegible]

15

193 - 219

FOLD OUT FRAME 2



PER COIT. FINANC

ASSEMBLY STRENGTHENING  
ABOUT THIS LINE.  
EIGHTY EIGHT

DETAIL of -17  
Scale 2:

1. 30 99 750 4000 5000 5000  
 2. 30 99 750 4000 5000 5000  
 3. 30 99 750 4000 5000 5000  
 4. 30 99 750 4000 5000 5000  
 5. 30 99 750 4000 5000 5000

DETAILS -13, -15, -16  
SCALE 1"

- 0760 1403 -

670 900,  
 8 8 0 9 4 9  
 4 35 15- 7 4  
 43.8 "  
 7-2 16 10 40  
 8 8 - 1 4 0  
 4 2 3 7 0  
 4 4 1 4

4 19 24 25 26

1. *Chlorophyll a* (Chl *a*)  
 2. *Chlorophyll b* (Chl *b*)  
 3. *Chlorophyll c* (Chl *c*)  
 4. *Chlorophyll d* (Chl *d*)  
 5. *Chlorophyll e* (Chl *e*)  
 6. *Chlorophyll f* (Chl *f*)  
 7. *Chlorophyll g* (Chl *g*)  
 8. *Chlorophyll h* (Chl *h*)  
 9. *Chlorophyll i* (Chl *i*)  
 10. *Chlorophyll j* (Chl *j*)  
 11. *Chlorophyll k* (Chl *k*)  
 12. *Chlorophyll l* (Chl *l*)  
 13. *Chlorophyll m* (Chl *m*)  
 14. *Chlorophyll n* (Chl *n*)  
 15. *Chlorophyll o* (Chl *o*)  
 16. *Chlorophyll p* (Chl *p*)  
 17. *Chlorophyll q* (Chl *q*)  
 18. *Chlorophyll r* (Chl *r*)  
 19. *Chlorophyll s* (Chl *s*)  
 20. *Chlorophyll t* (Chl *t*)  
 21. *Chlorophyll u* (Chl *u*)  
 22. *Chlorophyll v* (Chl *v*)  
 23. *Chlorophyll w* (Chl *w*)  
 24. *Chlorophyll x* (Chl *x*)  
 25. *Chlorophyll y* (Chl *y*)  
 26. *Chlorophyll z* (Chl *z*)  
 27. *Chlorophyll aa* (Chl *aa*)  
 28. *Chlorophyll ab* (Chl *ab*)  
 29. *Chlorophyll ac* (Chl *ac*)  
 30. *Chlorophyll ad* (Chl *ad*)  
 31. *Chlorophyll ae* (Chl *ae*)  
 32. *Chlorophyll af* (Chl *af*)  
 33. *Chlorophyll ag* (Chl *ag*)  
 34. *Chlorophyll ah* (Chl *ah*)  
 35. *Chlorophyll ai* (Chl *ai*)  
 36. *Chlorophyll aj* (Chl *aj*)  
 37. *Chlorophyll ak* (Chl *ak*)  
 38. *Chlorophyll al* (Chl *al*)  
 39. *Chlorophyll am* (Chl *am*)  
 40. *Chlorophyll an* (Chl *an*)  
 41. *Chlorophyll ao* (Chl *ao*)  
 42. *Chlorophyll ap* (Chl *ap*)  
 43. *Chlorophyll aq* (Chl *aq*)  
 44. *Chlorophyll ar* (Chl *ar*)  
 45. *Chlorophyll as* (Chl *as*)  
 46. *Chlorophyll at* (Chl *at*)  
 47. *Chlorophyll au* (Chl *au*)  
 48. *Chlorophyll av* (Chl *av*)  
 49. *Chlorophyll aw* (Chl *aw*)  
 50. *Chlorophyll ax* (Chl *ax*)  
 51. *Chlorophyll ay* (Chl *ay*)  
 52. *Chlorophyll az* (Chl *az*)  
 53. *Chlorophyll aza* (Chl *aza*)  
 54. *Chlorophyll abz* (Chl *abz*)  
 55. *Chlorophyll acz* (Chl *acz*)  
 56. *Chlorophyll adz* (Chl *adz*)  
 57. *Chlorophyll aez* (Chl *aez*)  
 58. *Chlorophyll afz* (Chl *afz*)  
 59. *Chlorophyll agz* (Chl *agz*)  
 60. *Chlorophyll ahz* (Chl *ahz*)  
 61. *Chlorophyll aiz* (Chl *aiz*)  
 62. *Chlorophyll ajz* (Chl *ajz*)  
 63. *Chlorophyll akz* (Chl *akz*)  
 64. *Chlorophyll alz* (Chl *alz*)  
 65. *Chlorophyll amz* (Chl *amz*)  
 66. *Chlorophyll anz* (Chl *anz*)  
 67. *Chlorophyll aoz* (Chl *aoz*)  
 68. *Chlorophyll apz* (Chl *apz*)  
 69. *Chlorophyll aqz* (Chl *aqz*)  
 70. *Chlorophyll arz* (Chl *arz*)  
 71. *Chlorophyll asz* (Chl *asz*)  
 72. *Chlorophyll atz* (Chl *atz*)  
 73. *Chlorophyll auz* (Chl *auz*)  
 74. *Chlorophyll avz* (Chl *avz*)  
 75. *Chlorophyll awz* (Chl *awz*)  
 76. *Chlorophyll axz* (Chl *axz*)  
 77. *Chlorophyll ayz* (Chl *ayz*)  
 78. *Chlorophyll ayz* (Chl *ayz*)  
 79. *Chlorophyll azz* (Chl *azz*)  
 80. *Chlorophyll azaa* (Chl *aza*)  
 81. *Chlorophyll abz* (Chl *abz*)  
 82. *Chlorophyll acz* (Chl *acz*)  
 83. *Chlorophyll adz* (Chl *adz*)  
 84. *Chlorophyll aez* (Chl *aez*)  
 85. *Chlorophyll afz* (Chl *afz*)  
 86. *Chlorophyll agz* (Chl *agz*)  
 87. *Chlorophyll ahz* (Chl *ahz*)  
 88. *Chlorophyll aiz* (Chl *aiz*)  
 89. *Chlorophyll ajz* (Chl *ajz*)  
 90. *Chlorophyll akz* (Chl *akz*)  
 91. *Chlorophyll alz* (Chl *alz*)  
 92. *Chlorophyll amz* (Chl *amz*)  
 93. *Chlorophyll anz* (Chl *anz*)  
 94. *Chlorophyll aoz* (Chl *aoz*)  
 95. *Chlorophyll apz* (Chl *apz*)  
 96. *Chlorophyll aqz* (Chl *aqz*)  
 97. *Chlorophyll arz* (Chl *arz*)  
 98. *Chlorophyll asz* (Chl *asz*)  
 99. *Chlorophyll atz* (Chl *atz*)  
 100. *Chlorophyll auz* (Chl *auz*)  
 101. *Chlorophyll avz* (Chl *avz*)  
 102. *Chlorophyll awz* (Chl *awz*)  
 103. *Chlorophyll axz* (Chl *axz*)  
 104. *Chlorophyll ayz* (Chl *ayz*)  
 105. *Chlorophyll ayz* (Chl *ayz*)  
 106. *Chlorophyll azz* (Chl *azz*)  
 107. *Chlorophyll azaa* (Chl *aza*)  
 108. *Chlorophyll abz* (Chl *abz*)  
 109. *Chlorophyll acz* (Chl *acz*)  
 110. *Chlorophyll adz* (Chl *adz*)  
 111. *Chlorophyll aez* (Chl *aez*)  
 112. *Chlorophyll afz* (Chl *afz*)  
 113. *Chlorophyll agz* (Chl *agz*)  
 114. *Chlorophyll ahz* (Chl *ahz*)  
 115. *Chlorophyll aiz* (Chl *aiz*)  
 116. *Chlorophyll ajz* (Chl *ajz*)  
 117. *Chlorophyll akz* (Chl *akz*)  
 118. *Chlorophyll alz* (Chl *alz*)  
 119. *Chlorophyll amz* (Chl *amz*)  
 120. *Chlorophyll anz* (Chl *anz*)  
 121. *Chlorophyll aoz* (Chl *aoz*)  
 122. *Chlorophyll apz* (Chl *apz*)  
 123. *Chlorophyll aqz* (Chl *aqz*)  
 124. *Chlorophyll arz* (Chl *arz*)  
 125. *Chlorophyll asz* (Chl *asz*)  
 126. *Chlorophyll atz* (Chl *atz*)  
 127. *Chlorophyll auz* (Chl *auz*)  
 128. *Chlorophyll avz* (Chl *avz*)  
 129. *Chlorophyll awz* (Chl *awz*)  
 130. *Chlorophyll axz* (Chl *axz*)  
 131. *Chlorophyll ayz* (Chl *ayz*)  
 132. *Chlorophyll ayz* (Chl *ayz*)  
 133.

學 生 證  
 1. 姓名: 張國強  
 2. 學號: 000000

70-4000  
100-6000  
200-8000

170

100 x 40

- 69 96 7 750, -  
 - 27 30 9 300) -  
 - 43 5 5 68) -  
 - 64 5 7 750)  
 - 24 30 9 300

482 2019 9 23 10:48

49° 30' 0.3301

2000  
 100 100 100 100  
 100 100 100 100

SE PAN \*JCL ASSY

1997

2

ASSEMBLY DIMENSIONS  
ABOUT THE LINE  
EXCEPT FOR HOLE

SEE DETAIL  
10-8-9

#### NOTES

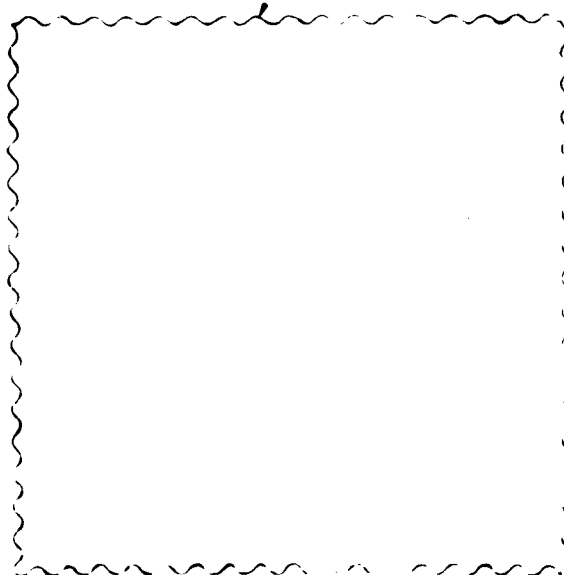
1. DIMENSIONS ARE IN INCHES AND DECIMALS THEREOF.
2. FINISH SHALL BE AS SHOWN.
3. TOLERANCES:  
FRACTIONS: ± 1/16, ± 1/32, ± 1/64  
DECIMALS: ± .01, ± .005, ± .001  
ANGLES: ± 1°, ± 1/2°, ± 1/4°
4. WELD FRAMES SHALL BE WELDED CORNERS TO MAKE A SQUARE.

PART NO.		DESCRIPTION		QTY		SPEC	
1	1	INLET TUBE	COSS	176-176	1/2	304	
2	1	UPPER PLATE	AL AL	15-15-15			
3	1	LOWER PLATE	AL AL	15-15-15			
4	1	TIE ROD	SPCL	20-20-20	C 310		
5	1	FRAME SIDE		20-15-15	ASTM A 36		
6	1	END - 10		70-55-15			
7	1	PLATED SIDE		70-55-15			
8	1	PLAIN SIDE		70-55-15			
9	1	BASE PLATE	SPCL	15-15-15	ASTM A 36		
10	1	CONNECTORS ON FRAME					
11	1	WELD TOOL ASSEMBLY					
12	1	WELD MARKER ASSEMBLY					
13	1	WELD TOOL ASSEMBLY					
14	1	WELD TOOL ASSEMBLY					
15	1	WELD TOOL ASSEMBLY					
16	1	WELD TOOL ASSEMBLY					
17	1	WELD TOOL ASSEMBLY					
18	1	WELD TOOL ASSEMBLY					
19	1	WELD TOOL ASSEMBLY					
20	1	WELD TOOL ASSEMBLY					
21	1	WELD TOOL ASSEMBLY					
22	1	WELD TOOL ASSEMBLY					
23	1	WELD TOOL ASSEMBLY					
24	1	WELD TOOL ASSEMBLY					
25	1	WELD TOOL ASSEMBLY					
26	1	WELD TOOL ASSEMBLY					
27	1	WELD TOOL ASSEMBLY					
28	1	WELD TOOL ASSEMBLY					
29	1	WELD TOOL ASSEMBLY					
30	1	WELD TOOL ASSEMBLY					
31	1	WELD TOOL ASSEMBLY					
32	1	WELD TOOL ASSEMBLY					
33	1	WELD TOOL ASSEMBLY					
34	1	WELD TOOL ASSEMBLY					
35	1	WELD TOOL ASSEMBLY					
36	1	WELD TOOL ASSEMBLY					
37	1	WELD TOOL ASSEMBLY					
38	1	WELD TOOL ASSEMBLY					
39	1	WELD TOOL ASSEMBLY					
40	1	WELD TOOL ASSEMBLY					
41	1	WELD TOOL ASSEMBLY					
42	1	WELD TOOL ASSEMBLY					
43	1	WELD TOOL ASSEMBLY					
44	1	WELD TOOL ASSEMBLY					
45	1	WELD TOOL ASSEMBLY					
46	1	WELD TOOL ASSEMBLY					
47	1	WELD TOOL ASSEMBLY					
48	1	WELD TOOL ASSEMBLY					
49	1	WELD TOOL ASSEMBLY					
50	1	WELD TOOL ASSEMBLY					
51	1	WELD TOOL ASSEMBLY					
52	1	WELD TOOL ASSEMBLY					
53	1	WELD TOOL ASSEMBLY					
54	1	WELD TOOL ASSEMBLY					
55	1	WELD TOOL ASSEMBLY					
56	1	WELD TOOL ASSEMBLY					
57	1	WELD TOOL ASSEMBLY					
58	1	WELD TOOL ASSEMBLY					
59	1	WELD TOOL ASSEMBLY					
60	1	WELD TOOL ASSEMBLY					
61	1	WELD TOOL ASSEMBLY					
62	1	WELD TOOL ASSEMBLY					
63	1	WELD TOOL ASSEMBLY					
64	1	WELD TOOL ASSEMBLY					
65	1	WELD TOOL ASSEMBLY					
66	1	WELD TOOL ASSEMBLY					
67	1	WELD TOOL ASSEMBLY					
68	1	WELD TOOL ASSEMBLY					
69	1	WELD TOOL ASSEMBLY					
70	1	WELD TOOL ASSEMBLY					
71	1	WELD TOOL ASSEMBLY					
72	1	WELD TOOL ASSEMBLY					
73	1	WELD TOOL ASSEMBLY					
74	1	WELD TOOL ASSEMBLY					
75	1	WELD TOOL ASSEMBLY					
76	1	WELD TOOL ASSEMBLY					
77	1	WELD TOOL ASSEMBLY					
78	1	WELD TOOL ASSEMBLY					
79	1	WELD TOOL ASSEMBLY					
80	1	WELD TOOL ASSEMBLY					
81	1	WELD TOOL ASSEMBLY					
82	1	WELD TOOL ASSEMBLY					
83	1	WELD TOOL ASSEMBLY					
84	1	WELD TOOL ASSEMBLY					
85	1	WELD TOOL ASSEMBLY					
86	1	WELD TOOL ASSEMBLY					
87	1	WELD TOOL ASSEMBLY					
88	1	WELD TOOL ASSEMBLY					
89	1	WELD TOOL ASSEMBLY					
90	1	WELD TOOL ASSEMBLY					
91	1	WELD TOOL ASSEMBLY					
92	1	WELD TOOL ASSEMBLY					
93	1	WELD TOOL ASSEMBLY					
94	1	WELD TOOL ASSEMBLY					
95	1	WELD TOOL ASSEMBLY					
96	1	WELD TOOL ASSEMBLY					
97	1	WELD TOOL ASSEMBLY					
98	1	WELD TOOL ASSEMBLY					
99	1	WELD TOOL ASSEMBLY					
100	1	WELD TOOL ASSEMBLY					

Figure 6. Design, Skin Forming Tool

PN 195-218





10 840  
1007

10 840  
1007

10 840  
1007

10 840  
1007

DETAIL OF BOLT HOLES  
SCALE 1/2"

END 1618

426 47  
426 47  
426 47  
426 47  
426 47

10 840  
1007

10 840  
1007

10 840  
1007

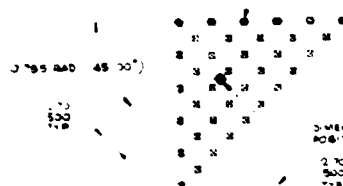


10 840  
1007

10 840  
1007

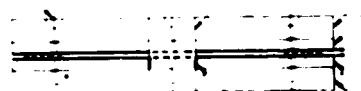
DETAIL OF BOLT HOLES  
SCALE 1/2"

FOLDOUT PAGE



DETAIL OF PIN PATTERN

LAB 45 - C



• 15

• 4 1-3

- 32 -

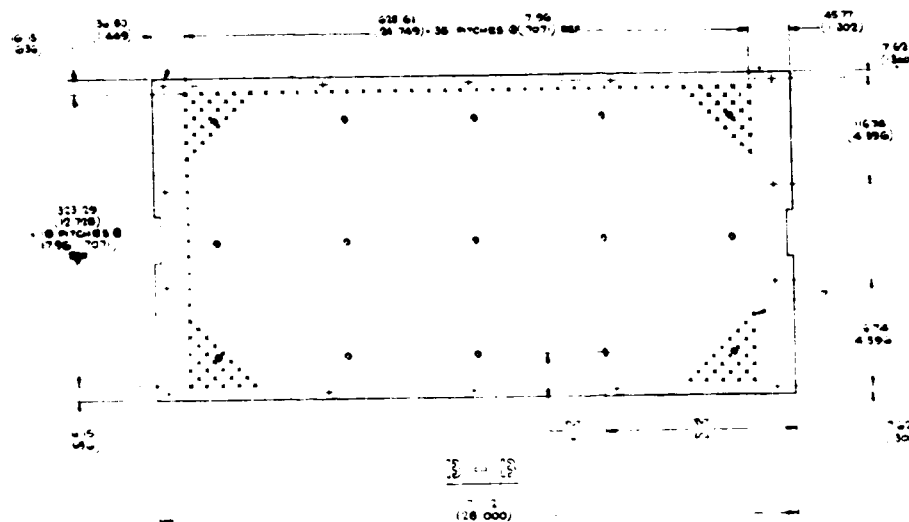
3 - 3

- 11 -

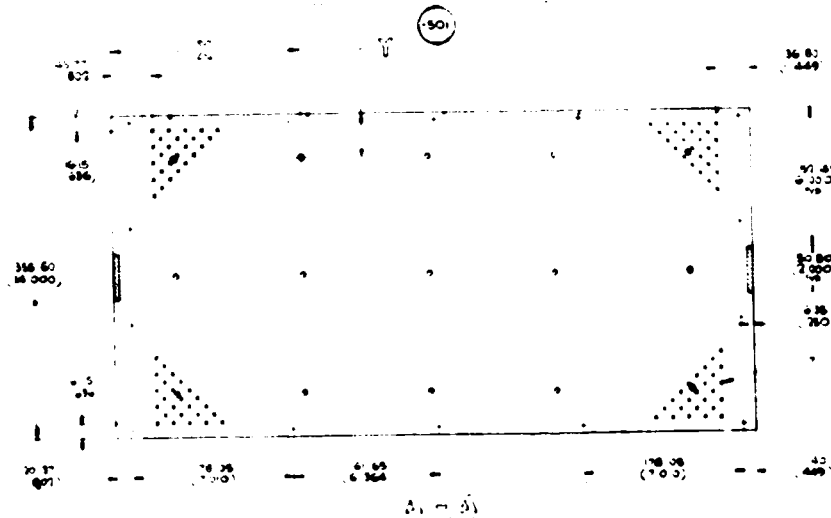
60 12	4 57	73 30	300 10
9 90	973	973	1 30
3			
9 163			
159 60			
4 300			
699 30			
4 657			
64 10	4 57	73 30	300 10
10 14	973	973	1 30

TABLE for BOLT HOLES

LP 16-6-2  
6 35 (25) DIA HOLE  
IN -23, THREAD  
-190-32 UNF-3B  
IN -13 28 PLCS



DETAIL & SIMPLE TOOL



**Figure**

התאריך: 10.01.2017



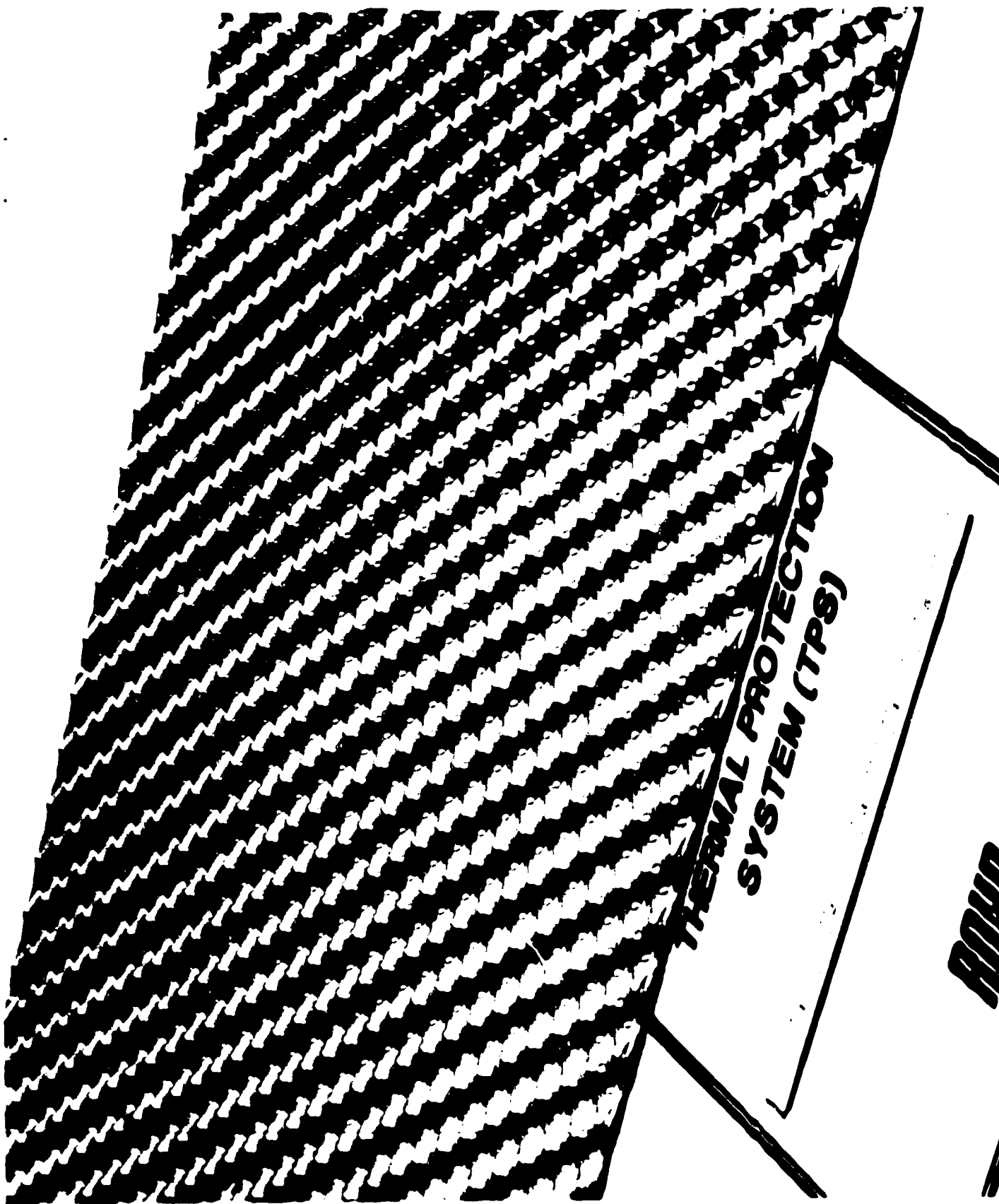


Figure 8. Superplastically Formed Ti-6Al-4V Dimpled Sheet (0.0076 x 30.5 x 61 cm (0.003 x 12 x 24 inches))



Figure 9. Superplastic Form Tool Ready for Loading Into Vacuum Furnace

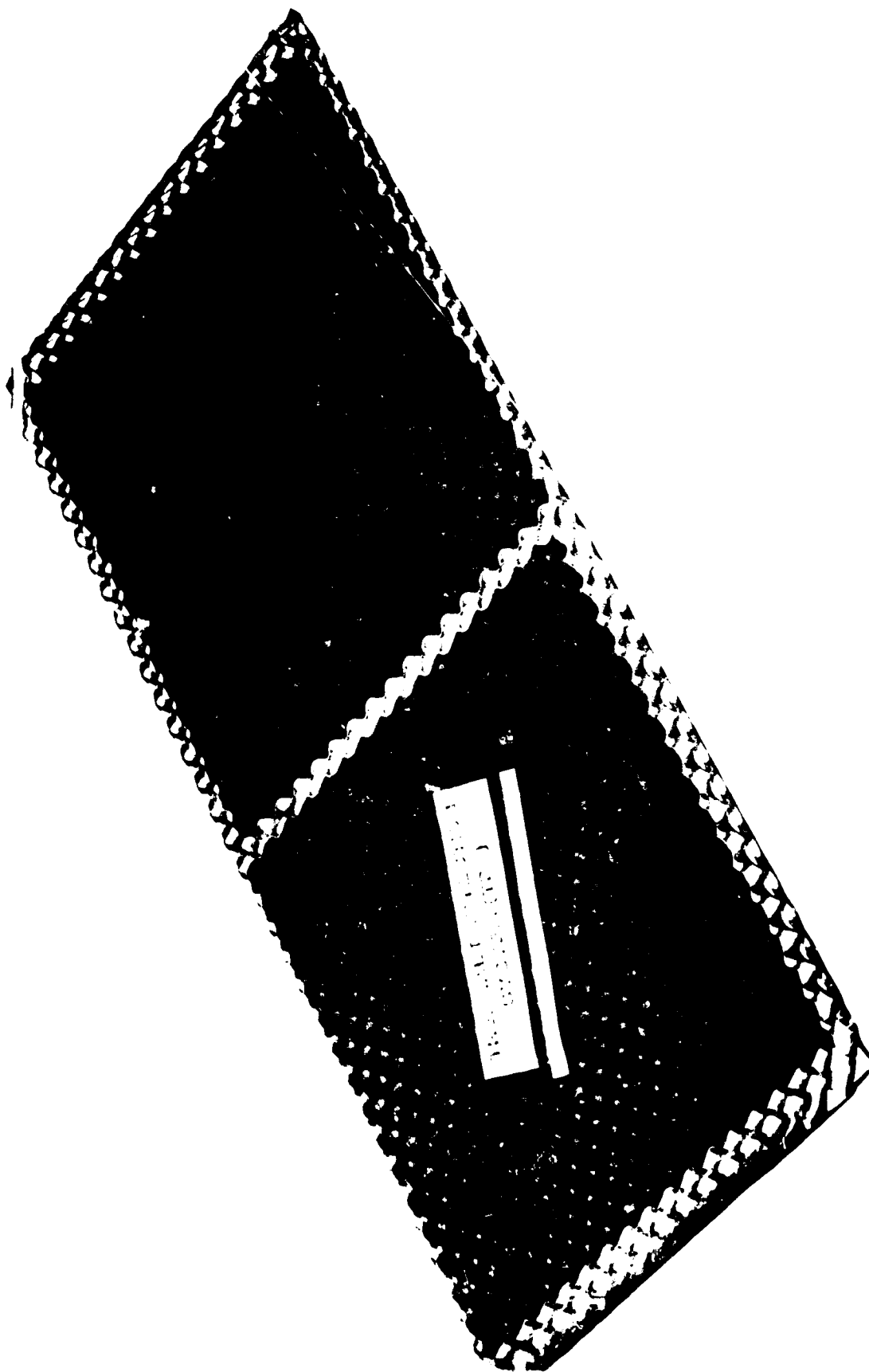


Figure 10. Dimpled Sheet Prepared for Chem-Blanking

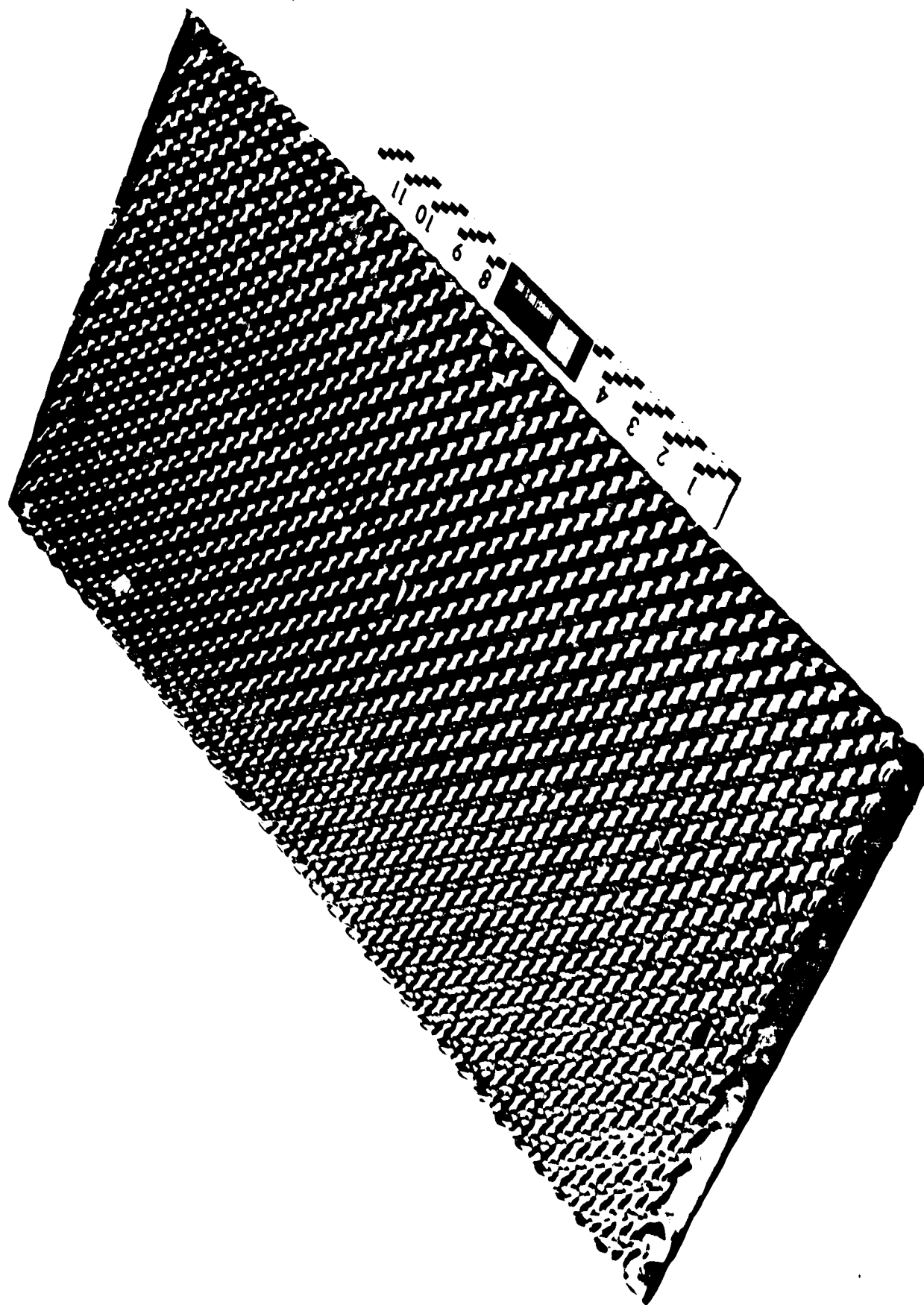


Figure 11. Plated Dimpled Sheet (Only the Node Flats Are Plated, Cutouts taken for Microexamination)

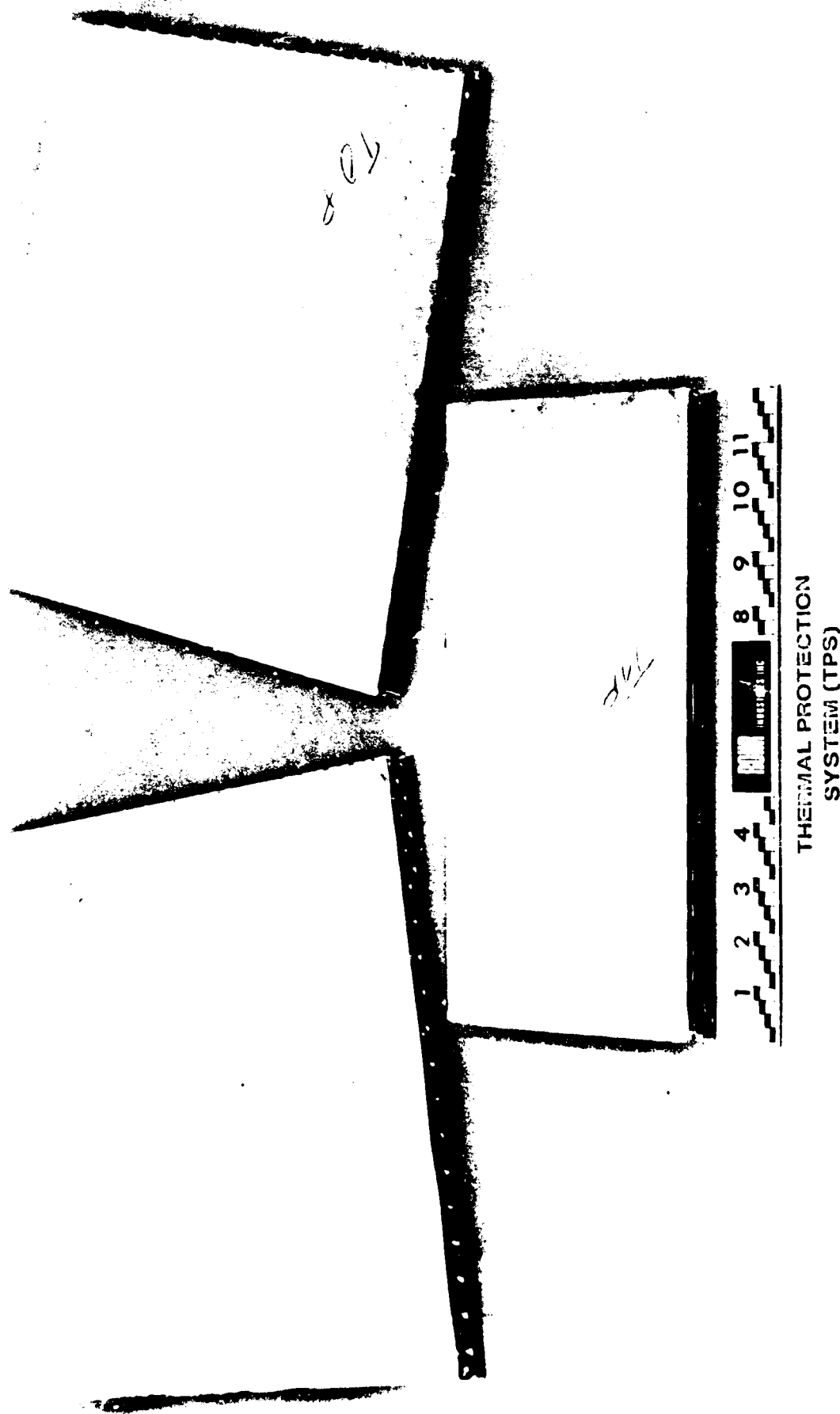


Figure 12. Multiwall Panels LID Bonded for Test Specimens



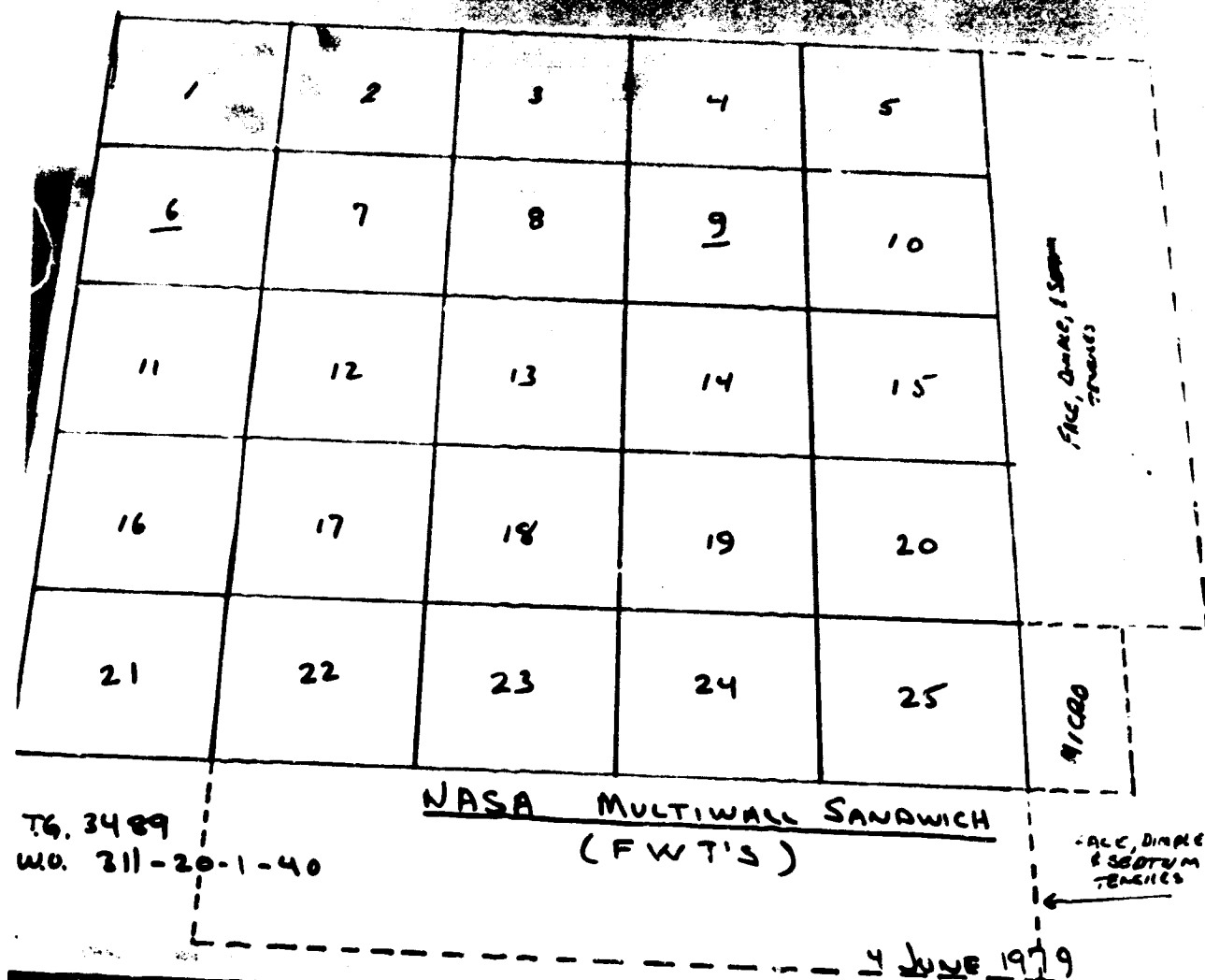


Figure 13. Beam Flexure Test Specimen Layout for Cutting Flatwise Face Tension, Tensile and Micro Specimens

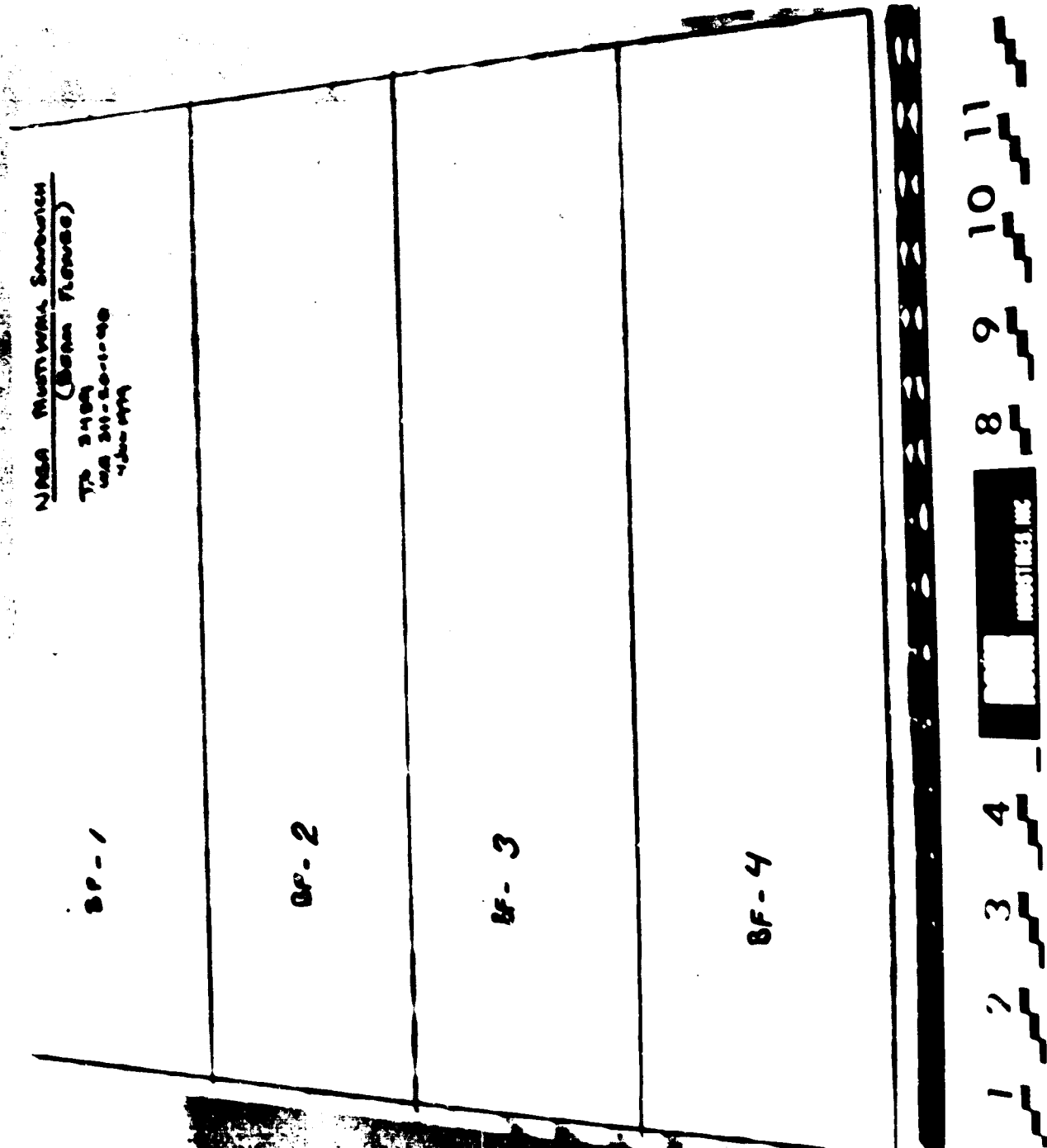


Figure 14. Beam Flexure Test Specimens Layout for Cutting Beam Flexure Test Specimens

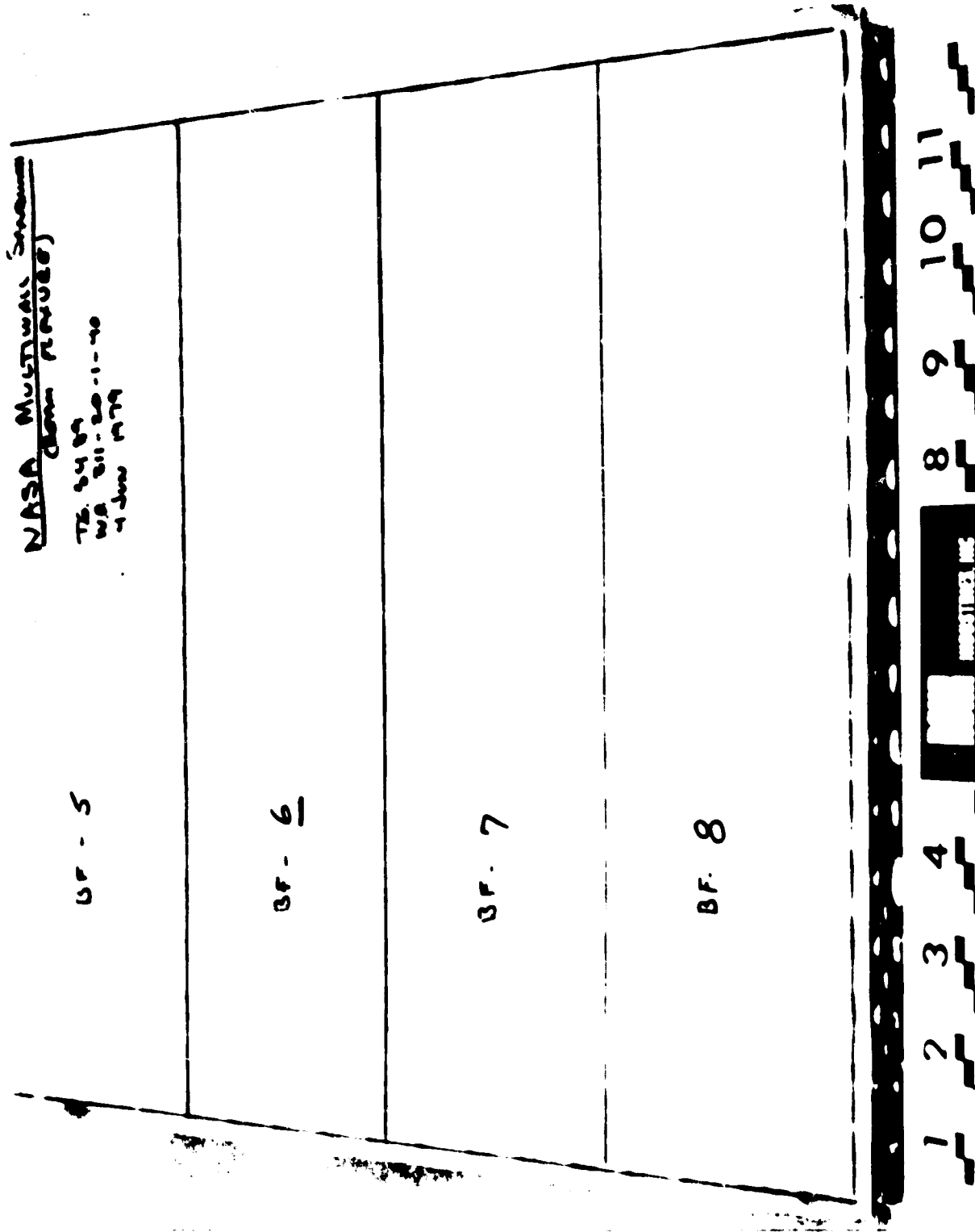


Figure 15. Flatwise Tension Test Specimen Layout for Cutting Beam Flexure Test Specimens

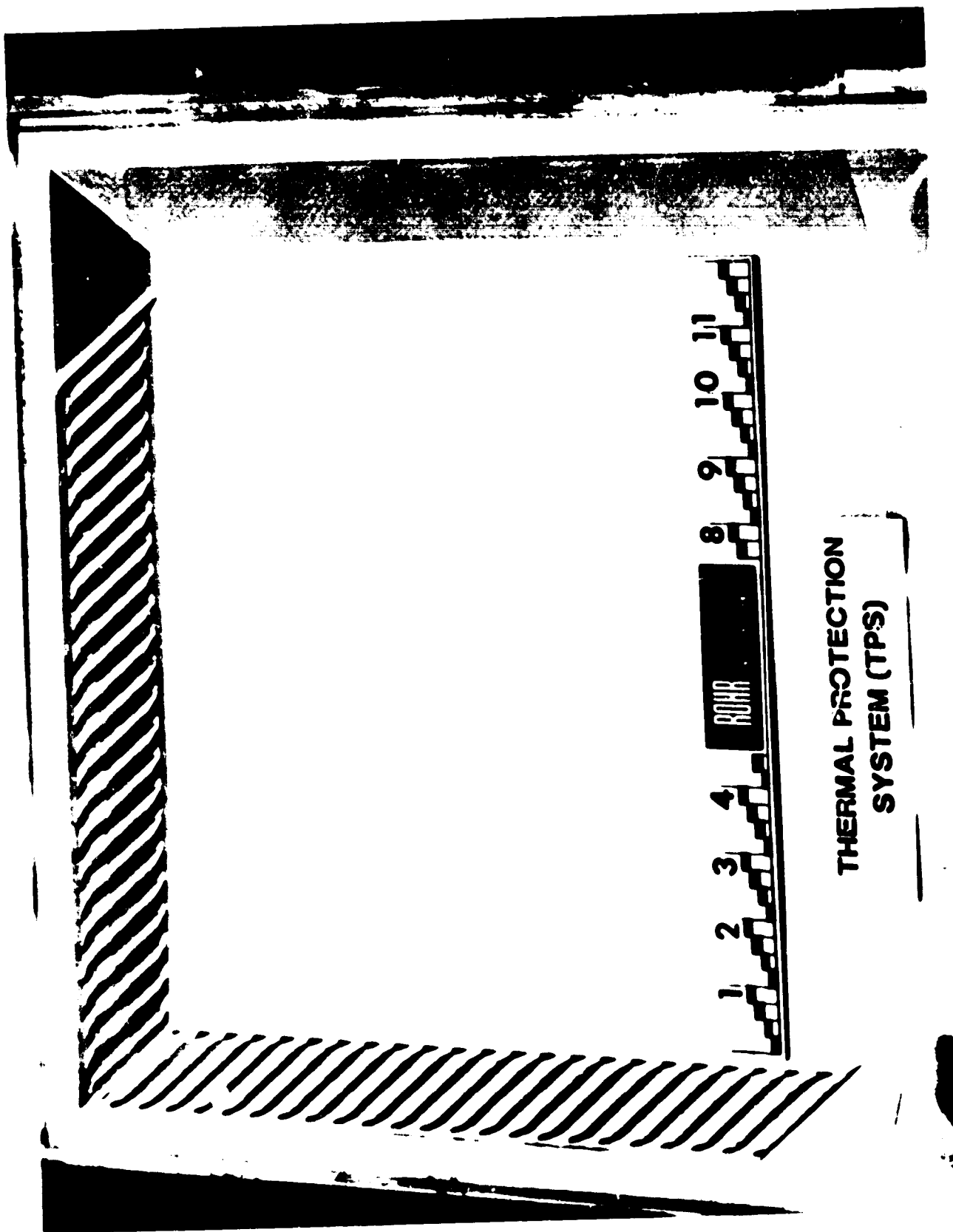


Figure 16. Superplastically Formed Skin - Ready to be Trimmed



Figure 17. Skin Form Tool - Ti-6Al-4V Sheets Being Installed in Tool for Superplastic Forming Skins  
(Which Also Close the Panel Sides)

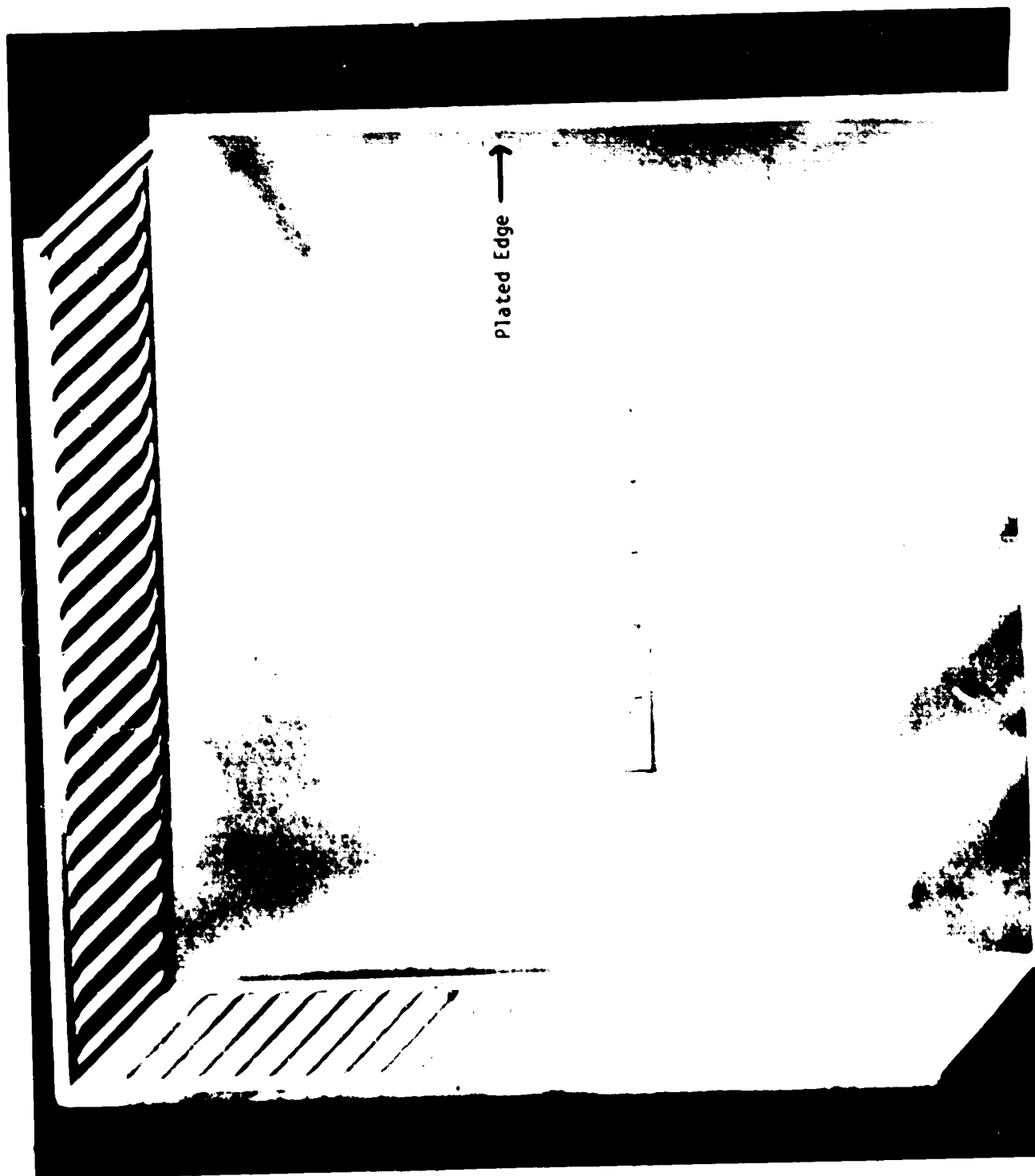


Figure 18. Plated Skin - Skin Has Edge Plated 5.1 mm (0.2-Inch) Wide for LID Bonding to Opposing Skin

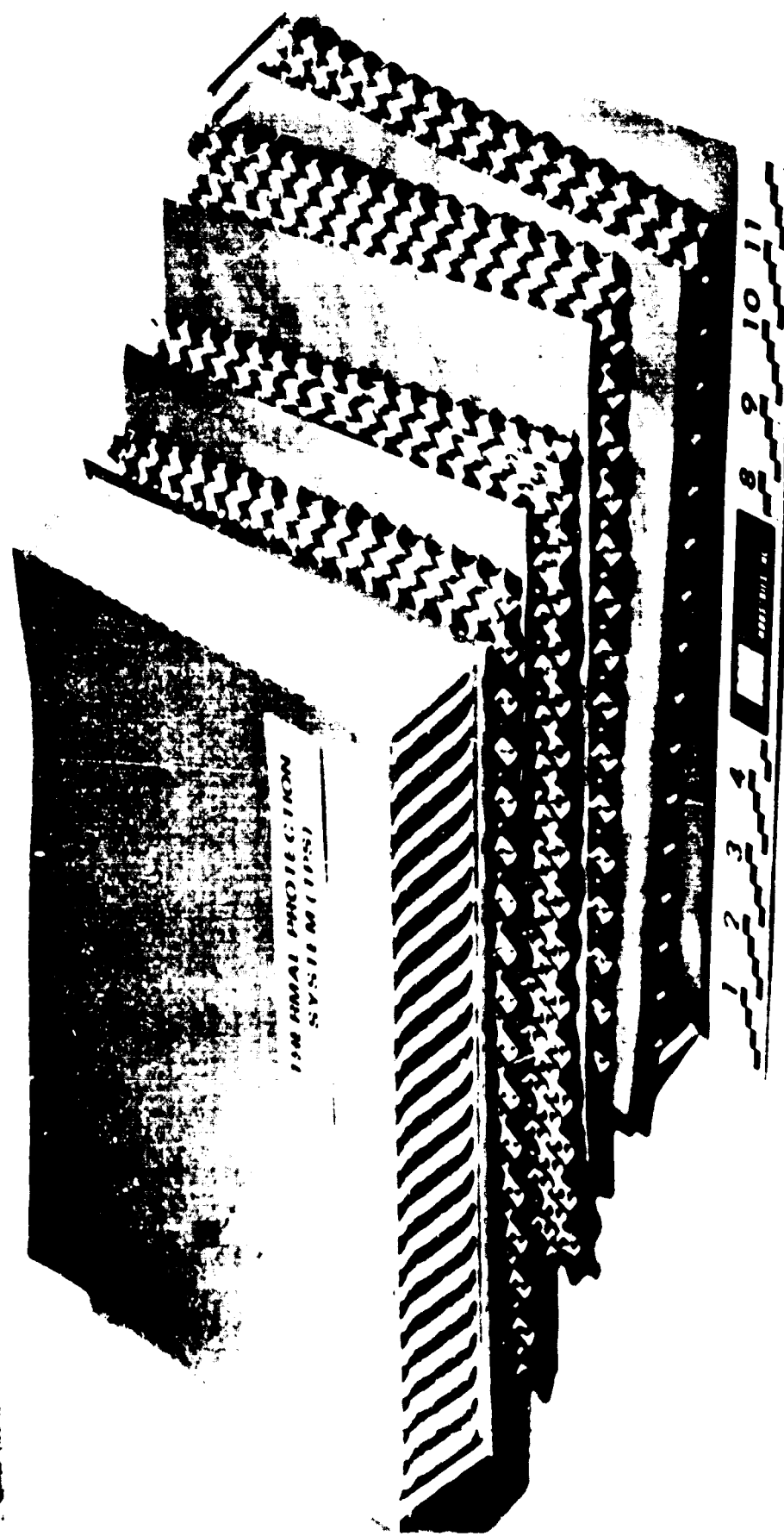


Figure 19. Dimpled Sheets, Septum Sheets and Skins Prepared for Assembly (Ready for Layup and LID Bonding)



Figure 20. Vacuum Tight Panel Test Panel Being Aided for LIP Bonding



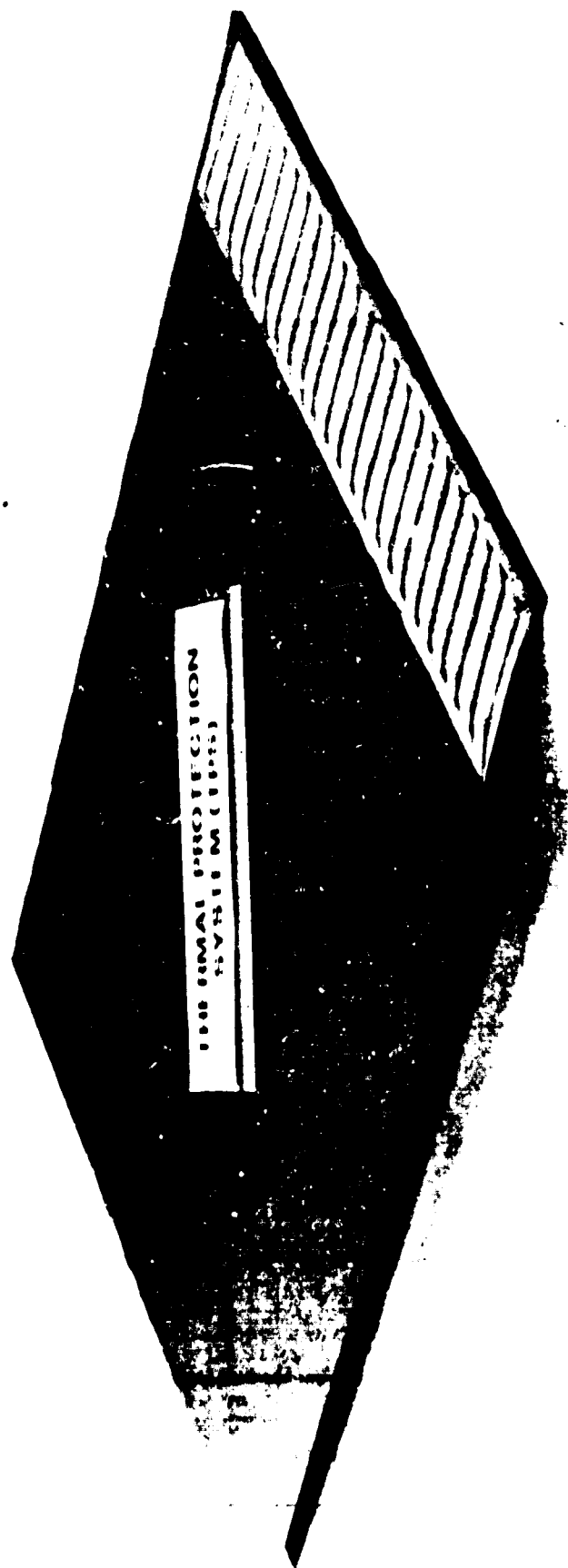


Figure 21. LID Bonded Panel (Vacuum Tight Evaluation)

# EMISSIONITY TEST RESULTS

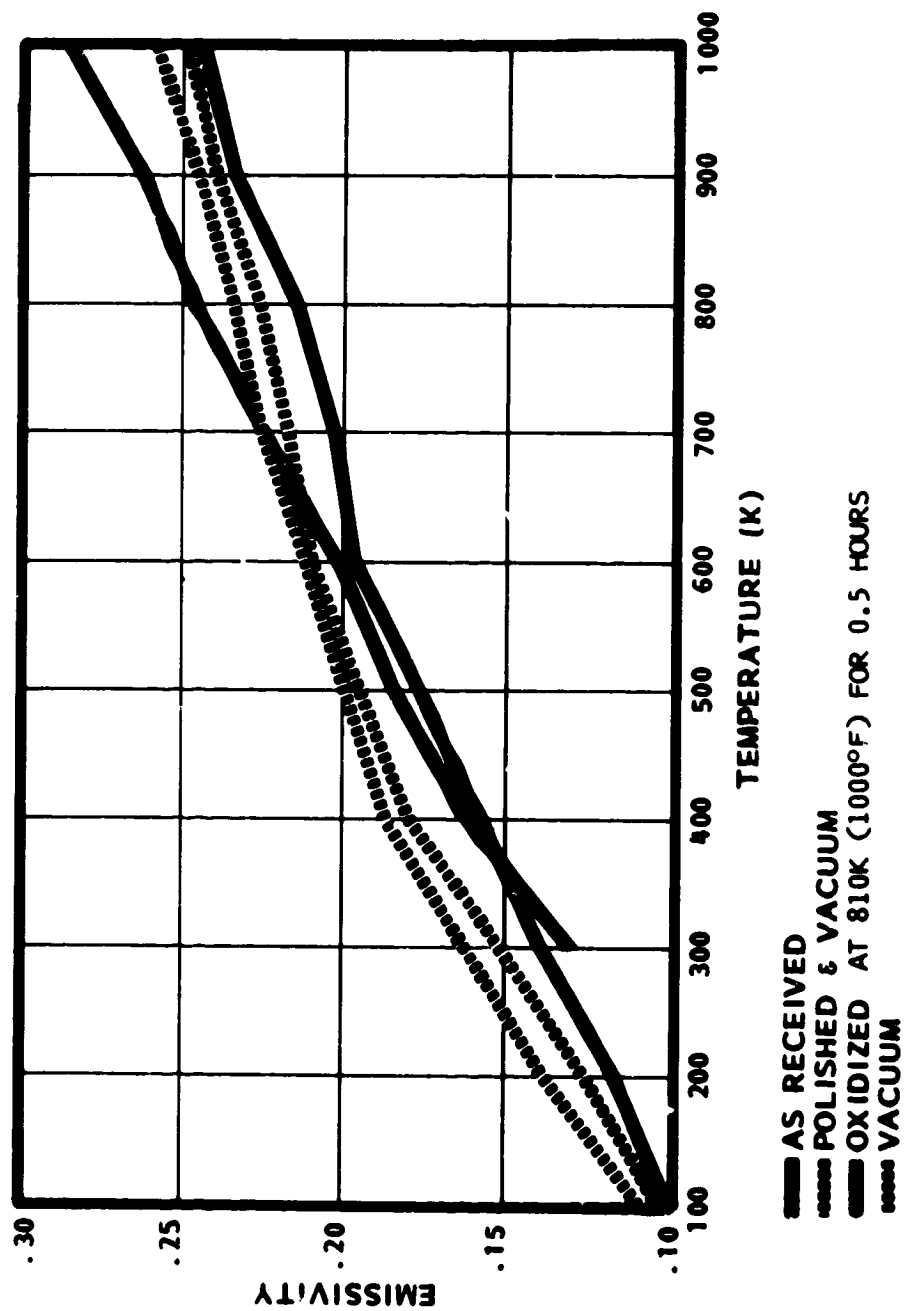


Figure 22. Emissionity Test Results

144004

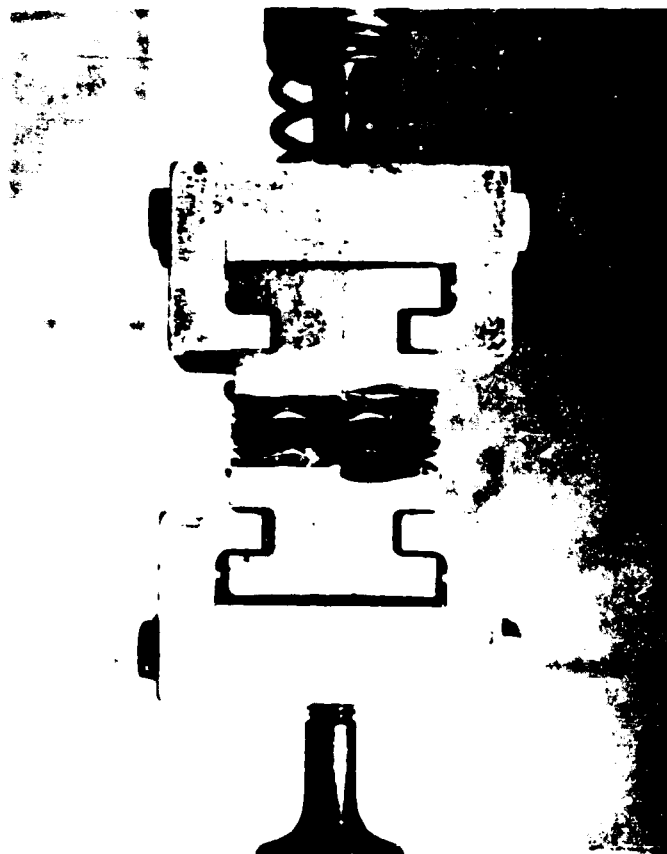


Figure 23. Test Fixture for Flatwise Tension Tests

ORIGINAL PAGE IS  
POOR QUALITY

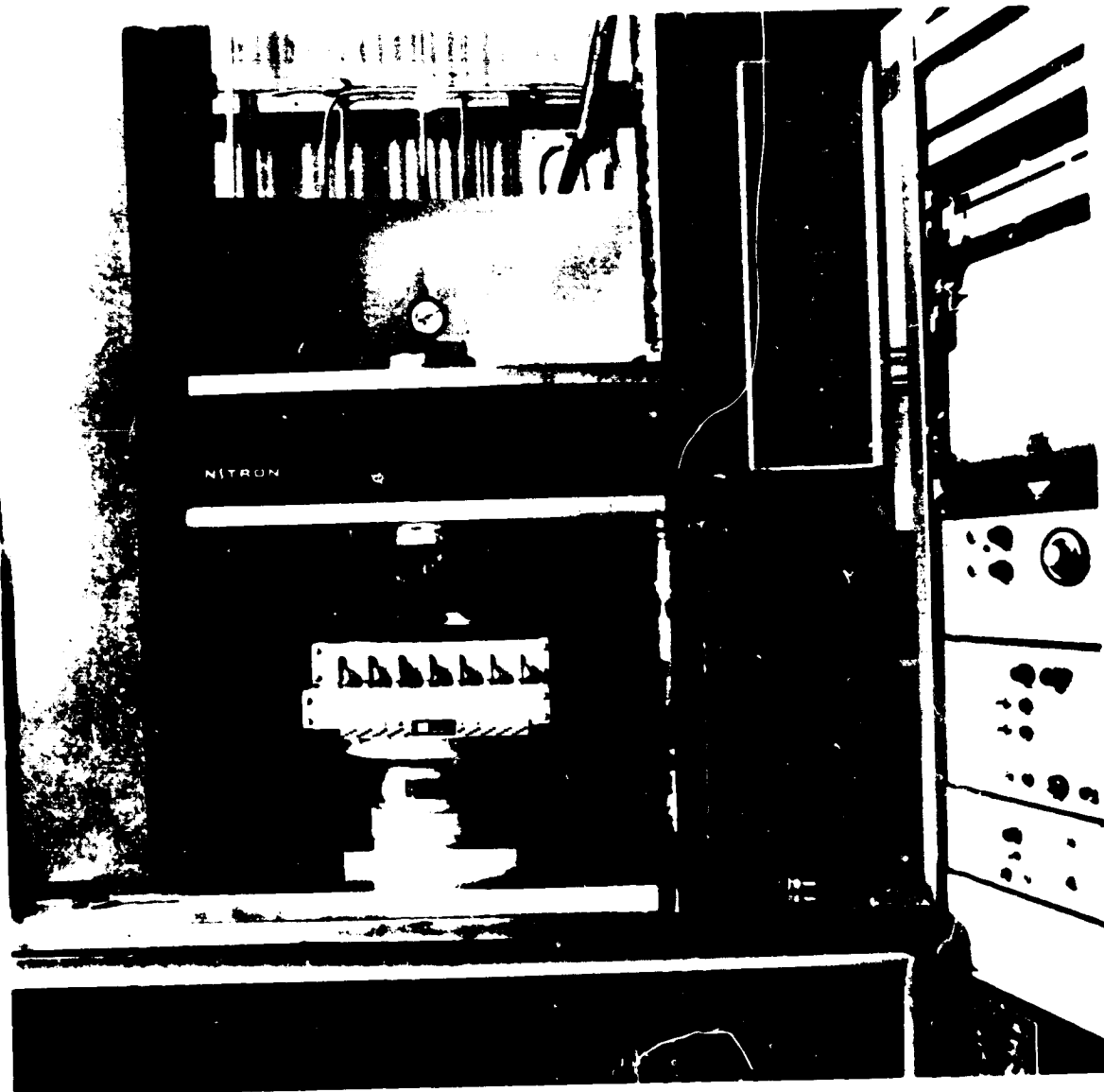
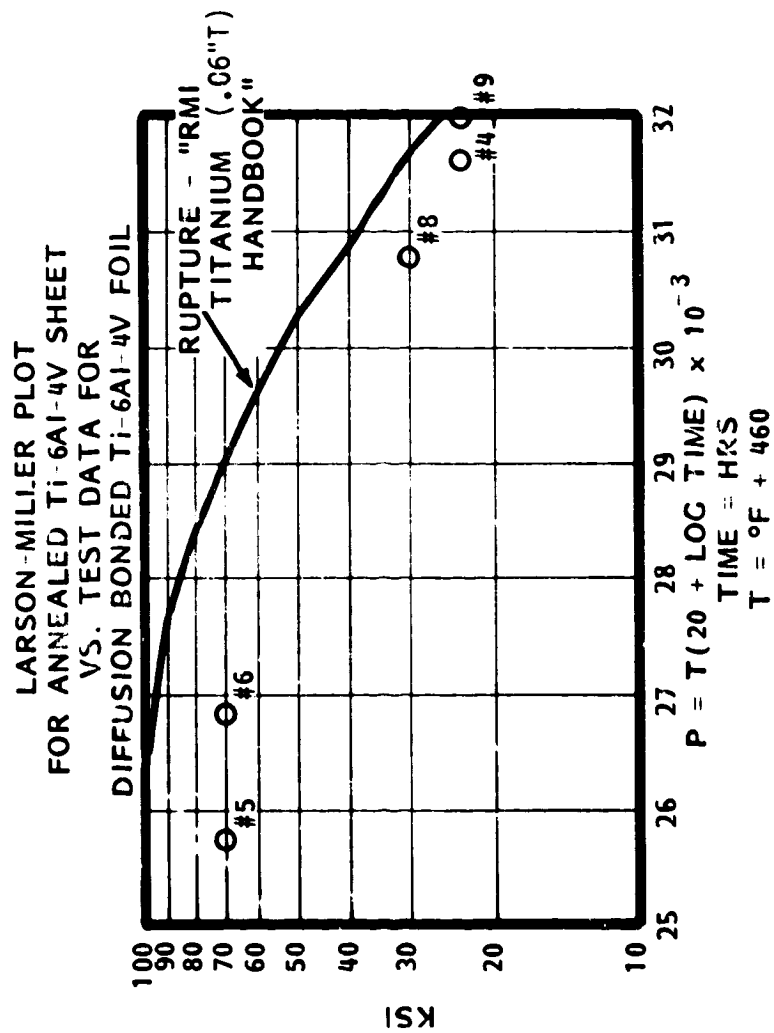


Figure 24. Test Setup for Hot Beam Flexure Tests



144043

Figure 25. Creep Test Results

TABLE I: EMITTANCE TEST DATA

Sample #7910		Sample #7911	
TEMPERATURE (KELVIN)	EMISSIVITY	TEMPERATURE (KELVIN)	EMISSIVITY
50	0.	50	0.
100	.1002E+00	100	.1030E+00
200	.1176E+00	200	.1361E+00
300	.1365E+00	300	.1655E+00
400	.1548E+00	400	.1809E+00
500	.1721E+00	500	.1976E+00
600	.1880E+00	600	.2121E+00
700	.2027E+00	700	.2251E+00
800	.2165E+00	800	.2369E+00
900	.2296E+00	900	.2471E+00
1000	.2420E+00	1000	.2581E+00
6050	.4518E+00	6050	.4324E+00

Sample #7912		Sample #7904	
TEMPERATURE (KELVIN)	EMISSIVITY	TEMPERATURE (KELVIN)	EMISSIVITY
50	0.	50	0.
100	.1041E+00	100	.1037E+00
200	.1275E+00	200	.1172E+00
300	.1507E+00	300	.1360E+00
400	.1706E+00	400	.1555E+00
500	.1878E+00	500	.1722E+00
600	.2035E+00	600	.2055E+00
700	.2164E+00	700	.2274E+00
800	.2282E+00	800	.2490E+00
900	.2389E+00	900	.2673E+00
1000	.2487E+00	1000	.2853E+00
6050	.4332E+00	6050	.4275E+00

Sample #7910 As Received  
 Sample #7911 Through manufacturing process  
 Sample #7912 Polished then through manufacturing process  
 Sample #7904 Oxidized

ORIGINAL PAGE IS  
 OF POOR QUALITY

TABLE 2  
FLATWISE TENSION TESTS  
SEPARATE LAYERS OF SANDWICH

LAYER 1		LAYER 2		LAYER 3		LAYER 4	
SPECIMEN NO.	FAILING STRESS, KPa (psi)	SPECIMEN NO.	FAILING STRESS, KPa (psi)	SPECIMEN NO.	FAILING STRESS, KPa (psi)	SPECIMEN NO.	FAILING STRESS, KPa (psi)
10-1	150 (22)	15-2	160 (23)	10-3	140 (20)	14-4	300 (44)
11-1	210 (30)	16-2	28 4 <sup>(1)</sup>	12-3	190 (27)	15-4	230 (34)
12-1	170 (24)	17-2	130 (19)	13-3	170 (24)	16-4	190 (28)
13-1	300 (44)	23-2	150 (22)	18-3	190 (27)	17-4	170 (24)
18-1	340 (49)	24-2	100 (15)	19-3	300 (43)	22-4	260 (38)
19-1	320 (46)	25-2	97 (14)	20-3	83 (12)	23-4	190 (28)
21-1	180 (26)	22-2	35 ( 5) <sup>(1)</sup>	21-3	160 (23)	24-4	41 ( 6) <sup>(1)</sup>
20-1	150 (22)					25-4	270 (39)
Avg.	230 (33)		100 (15)		170 (25)		210 (30)

(1) Microscopic examination of the failed surface indicated a good diffusion bond. Peeling loads from test setup suspected. See write up.

TABLE 3  
FLATWISE TENSION TESTS  
FULL DEPTH SANDWICH

SPECIMEN NO.	FAILURE LOAD N, (LBS.)	FAILURE STRESS KPa (PSI)	LOCATION OF FAILURE
1	400 (90)	157 (22.7)	Septum 1/Core 2
2	367 (82.5)	143 (20.8)	Septum 1/Core 2
3	351 (79)	137 (19.9)	Septum 2/Core 3
4	371 (83.5)	145 (21.0)	Septum 2/Core 3
5	291 (65.5)	114 (16.5)	Septum 2/Core 3
6	378 (85)	148 (21.5)	Septum 1/Core 2
7	287 (64.5)	112 (16.3)	Septum 1/Core 2
8	222 (50)	88 (12.7)	Septum 1/Core 2
9	267 (60)	104 (15.1)	Septum 1/Core 2
Avg.	326 (73.3)	185 (18.5)	



TABLE 4

## BASIC FACE SHEET TENSION TESTS - ROOM TEMPERATURE

Configuration	.04 mm (.0015")			.08 mm (.003")			.1 mm (.004")		
	F <sub>ty</sub> , Mpa (ksi)	F <sub>tu</sub> , Mpa (ksi)	e	F <sub>ty</sub> , Mpa (ksi)	F <sub>tu</sub> , Mpa (ksi)	e	F <sub>ty</sub> , Mpa (ksi)	F <sub>tu</sub> , Mpa (ksi)	e
As Received	1098 (159.3)	1351 (195.9)	3.8	926.0 (133.0)	1193 (173.1)	6.7	952.2 (138.1)	1121 (162.6)	9.3
After LID Thermal Cycle	1028 (149.1)	1022 (157.0)	1.0	910.1 (132.0)	1062 (154.0)	4.7	876.3 (127.1)	996.3 (144.5)	9.0
After LID Bonded and Core Removed	N/P	839.8 (121.8*)	.0*	950.1 (137.8)	950.1 (137.8)	.6	958.4 (139.0*)	1022 (148.2*)	12.9*

All values are an average of (3) except those marked by \* which are an average of (5).

TABLE 5  
BEAM FLEXURE TESTS

SPECIMEN NO.	MAX. TEMP. RANGE TENS. SIDE, ° ( F )	MAX. TEMP. RANGE COMP. SIDE, ° ( F )	FAILURE LOAD P., (LBS.) (1)	FAILURE MODE
BF-1	RT	RT	645# (145)	Disbond of .004 (102 $\mu$ m) face sheet at center of panel due to severe buckling
BF-2	RT	RT	600# (135)	Same as above
BF-3	410-429° (272-312)	679-706° (763-814)	429# (110)	Core shear instability at inner supports
BF-5	412-426° (253-306)	678-706° (760-810)	556# (125)	Same as above
BF-6	411-419° (280-294)	721-811° (946-999)	323# (26)	Same as above
BF-7	408-422° (274-300)	724-809° (951-997)	400# (90)	Same as above
BF-8	422-444° (300-340)	789-809° (960-997)	120# <sup>(2)</sup> (27)	No failure

(1) This numerical value is also equivalent to the value of the maximum bending moment, ft-m (in-lbs).

(2) This is the sustained applied load without failure.

## APPENDIX

A

REPORT NO. CASD-RTC-001

P. O. Y21778NR

THERMAL CONDUCTIVITY OF TITANIUM  
SANDWICH INSULATION

Prepared by  
General Dynamics Convair Division  
San Diego, CA

for  
Rohr Industries, Inc.  
Chula Vista

June, 1979

## INTRODUCTION

Thermal conductivity of a titanium foil sandwich panel supplied by Rohr Industries was measured in air at four temperatures from ambient to 800F on a guarded hot plate apparatus. Measurements were made by General Dynamics Convair Divisions' Physical Properties Laboratory.

## TEST SPECIMENS

The test specimens consisted of two panels 8" x 8" x approximately .68". They were composed of a multi-layer convoluted titanium foil core with titanium foil face sheets. Edges were open.

## TEST METHOD

Measurements were made on a guarded hot plate apparatus custom-built for the measurements. The apparatus is shown schematically in Figure 1. It consists of a pair of identical test panels with a thin guarded heater sandwiched between. The outer face of each panel is in contact with another heater assembly. Both faces of both panels and all four heaters (center, guard and 2 cold-face) are instrumented with thermocouples for temperature measurements. The entire assembly is lightly clamped together and encased in several layers of glass fabric insulation.

Measurements are made by adjusting electrical power to all heaters to establish the desired hot and cold face temperatures. Power to the guard heater is adjusted to establish the same temperature in the center and guard areas of the hot face to prevent lateral heat flow.

When equilibrium has been reached, conductivity is calculated from the center heater power, the center area, the specimen thickness and the temperature difference between the hot and cold faces using:

$$K = \frac{(I \cdot E/2) \cdot t}{A \cdot \Delta T}$$

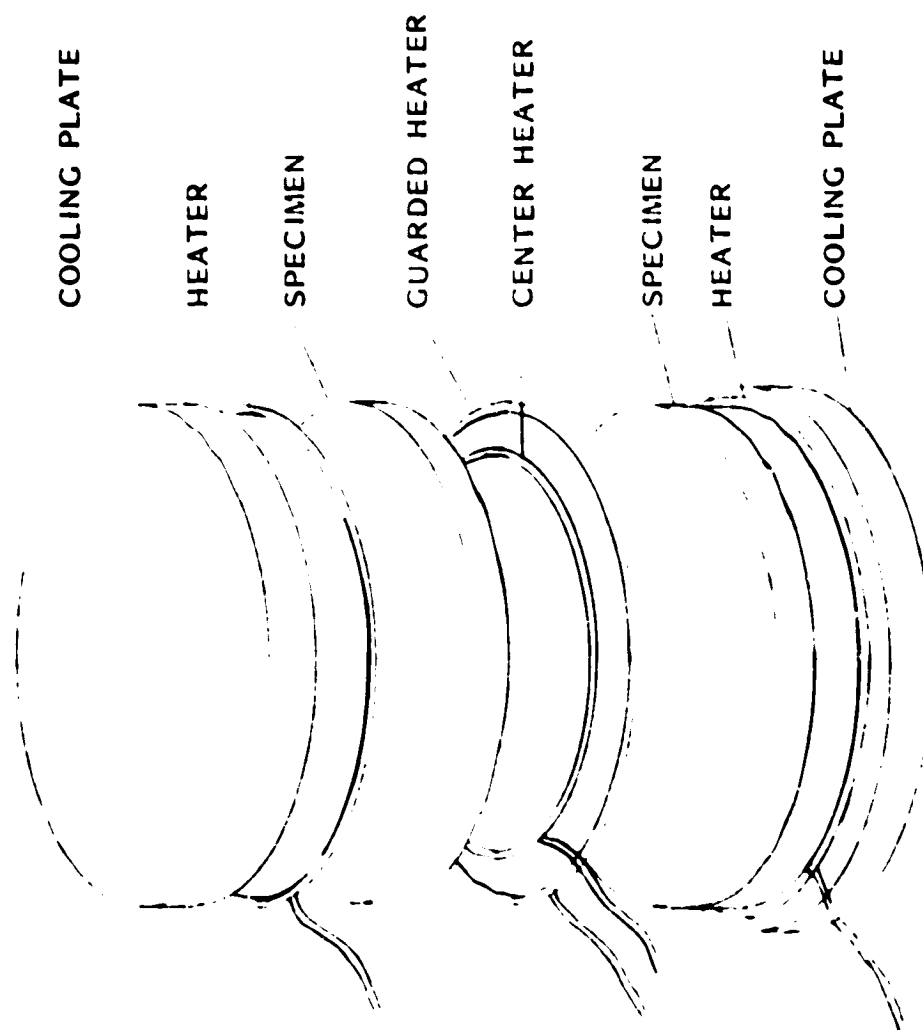
## TEST RESULTS

Conductivity values measured are shown in Table 1. They are reportedly higher by approximately 50% than analytical values provided to the requester. Excessive air flow through the specimen was suspected and points were repeated at ambient and 750F with tighter edge insulation and with the stack vertical instead of horizontal. As the data shows, there were no effects significant enough to explain these differences.\*

TABLE 1. TEST RESULTS

Mean T (F)	$\Delta T$ (F)	K (BTU/HR-FT-F)	Comments
83.3	18.6	.035	Horizontal, loose fiber glass insulation on edges
255.3	24.7	.067	Horizontal, loose fiber glass insulation on edges
500.0	20.0	.100	Horizontal, loose fiber glass insulation on edges
746.0	50.0	.128	Horizontal, loose fiber glass insulation on edges
93.8	14.5	.039	Horizontal, tight dynaquartz insulation on edges
93.2	13.3	.041	Vertical, tight dynaquartz insulation on edges
733.5	32.0	.126	Horizontal, tight dynaquartz insulation on edges
736.0	30.0	.133	Vertical, tight dynaquartz insulation on edges

\*Note: Subsequent to the tests by General Dynamics reported in this Appendix, conductivity measurements were made by Rohr Industries on a 305 x 305 mm (12 x 12 inch) panel. Results from these additional tests have been added to the figure in this Appendix. Also shown is an analytical curve calculated from NASA CP-2065.

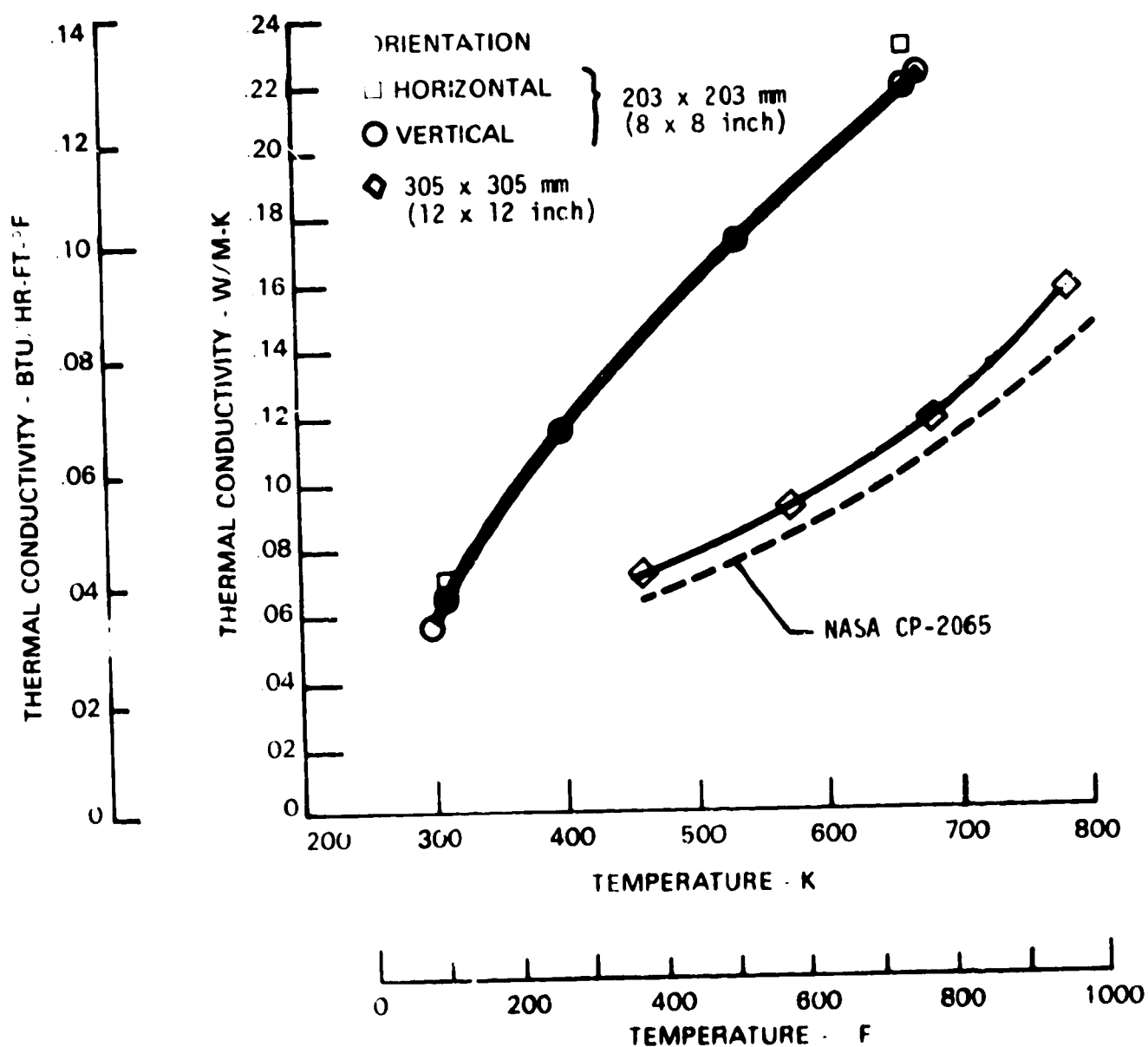


SCHEMATIC OF GUARDED HOT PLATE  
THERMAL CONDUCTIVITY APPARATUS

144068



Mean T (F)	$\Delta T$ (F)	K (BTU/HR-FT-F)	Comments
83.3	18.6	.035	Horizontal, loose fiber glass insulation on edges
255.3	24.7	.067	Horizontal, loose fiber glass insulation on edges
500.0	20.0	.100	Horizontal, loose fiber glass insulation on edges
746.0	50.0	.128	Horizontal, loose fiber glass insulation on edges
93.8	14.5	.039	Horizontal, tight dynaquartz insulation on edges
93.2	13.3	.041	Vertical, tight dynaquartz insulation on edges
733.5	32.0	.126	Horizontal, tight dynaquartz insulation on edges
736.0	30.0	.133	Vertical, tight dynaquartz insulation on edges



THERMAL CONDUCTIVITY VS. TEMPERATURE